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**TECHNOLOGY FOR MANPOWER,
PERSONNEL, TRAINING, AND SAFETY
(MPTS) TRADE-OFF DECISIONS**

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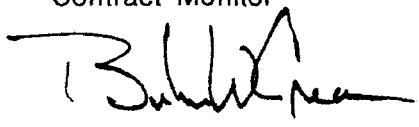
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FOREWORD

"Technology for Manpower, Personnel, Training, and Safety (MPTS) Tradeoff Decisions" requests the development of computer-based technology to integrate MPTS and human factors (HF). This integration is to occur under the Logistics Support Analysis Record umbrella, with emphasis on exploiting computer-aided design (CAD) and man-modeling technology. The proposed effort responds most directly to the manpower, personnel, and training (MPT) and CAD portions of this requirement, seeking further integration through the reliability (R&M) engineering design interface rather than the HF and safety design interface.

The central tenet of this effort is that the most direct integration of MPT into system design is through R&M engineering. The R&M interface is the primary determinant of the nature and volume of the workload that the maintenance force will experience. HF and safety interfaces deal with issues such as package size, displays, connectors, etc., which help determine how long a given task will take, but do not influence its frequency or nature. HF inputs generally come in the form of static design guidelines and are not interactive with any part of the system except physical layout. Decisions about constituent equipment are generally made with reference to mission requirements and to R&M estimates. These R&M parameters are only obliquely related to the manpower required to service the emerging system and are not interactive with them.

The approach to increasing the integration between R&M and manpower developed features a proactive manpower/R&M translation tool to support system design tradeoffs among reliability, maintainability, and the profile of AFSSs required to support design changes. This previously demonstrated approach will also feature a training and personnel quality requirement estimation, based upon the baseline comparison system. This portion of the proposed system is, essentially, an integration of the logistic support analysis and instructional system development processes.

This Phase I effort identifies the major functional requirements for an integrated MPT/R&M analysis tool, proposes an approach to meet these requirements, and assesses the feasibility and risks of a Phase II project to develop and demonstrate such a system.

PREFACE

This effort was performed for the Armstrong Laboratory, Logistics Research Division, Acquisition Logistics Branch, under the terms of Contract Number F41624-91-C-5001. Research was performed by the Dayton regional office of Systems Exploration, Inc. The principal investigator was Mr. Terry M. Miller

Johnny Jernigan and Theodore Meyers, both formerly of Systems Exploration, Inc., provided helpful inputs. Thanks also to Dr. Barry Deer of Netrollogic and Major Greg Clark, Major Bill Weaver, and Mr. Dick Cronk of the Air Force for help with manpower estimating models.

ABBREVIATIONS AND ACRONYMS

AFB	Air Force Base
AFLC	Air Force Logistic Command
ADPA	Apple Programmer's and Developer's Association
AFM	Air Force Manual
AFS	Air Force Specialty
ASVAB	Armed Services Vocational Aptitude Battery
BCS	Baseline Comparable System
BFS	Baseline Functional System
BPS	Baseline Physical System
CAD	Computer-aided Design
CALS	Computer-aided Acquisition & Logistics Support
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CE	Concurrent Engineering
CHRT	Coordinated Human Resources Technology
DEM/VAL	Demonstration/Validation
DoD	Department of Defense
DSS	Decision Support System
FMECA	Failure Modes, Effects, and Criticality Analysis
GFE	Government-furnished Equipment
HF	Human Factors
ILSP	Integrated Logistics Support Plan
IMACAD	Integrating Manpower Analysis with Computer-aided Design
IMPACTS	Integrated Manpower, Personnel, and Comprehensive Training and Safety
ISD	Instructional System Development
LCOM	Logistics Composite Model
LSA	Logistics Support Analysis
LSAR	Logistics Support Analysis Record
MAC	Months After Contract
MER	Manpower Estimate Report
MIL-STD	Military Standard
MMH/FH	Maintenance Man-hours per Flight Hour
MODAS	Maintenance and Operational Data Access System
MPT	Manpower, Personnel, and Training
MPTS	Manpower, Personnel, Training, and Safety
NMCM	Non-mission-capable Maintenance
NMCS	Non-mission-capable Supply
OJT	On-the-job Training

PAA	Primary Aircraft Authorization
PDR	Preliminary Design Review
PMEL	Precision Measuring Equipment Laboratory
PROD/DEPL	Production/Deployment
R&D	Research and Development
R&M	Reliability and Maintainability
S ³	Specialty Structuring System
SEI	Systems Exploration, Incorporated
SUMMA	Small Unit Maintenance Manpower Analysis
SW	Software
TAC	Tactical Air Command
TDSTL	Top-down Systems Tool for Logistics
TPDC	Training and Personnel Data Center
TTF	Time to Failure
TTR	Time to Repair
WUC	Work Unit Code

I. INTRODUCTION

The Small Business Innovative Research Phase I results presented in this report comprise an overview and analysis of current design practices covering Manpower, Personnel, and Training (MPT) issues; detailed descriptions of an approach to overcome some of the current impediments to MPT integration; a proposed workstation-based architecture to implement some of these ideas; and a proposed development program leading to a demonstration of an MPT/system design trade-off workstation.

The rationale underlying this particular MPT integration approach is:

- 1) Our goal is to increase the responsiveness of design to MPT centered logistics issues.
- 2) The design interfaces for logistics are through human factors (HF), which is often grouped with Safety, and through Reliability and Maintainability (R&M) engineering. HF provides design input to the system mainly as design requirements and standards, compliance with which is determined at several points during the design process. R&M parameters are performance estimates derived from the system functional and physical design characteristics. R&M estimates for an emerging design are compared against R&M targets set at the beginning of the effort.
- 3) Manpower, not reliability, not maintainability, drives MPT logistic costs. Other logistic issues (e.g., sparring, support equipment) are driven by R&M parameters. The relationship between R&M and Manpower estimates is a tortuous complex. Because of this problem, R&M goals are used as management controls for the MPT logistic profile of a system. Trade-offs among MPT and R&M are unavailable to the design team. As a consequence, designers sacrifice MPT issues instead of optimizing them.
- 4) Quantitative Personnel and Training calculations are dependent upon Manpower estimates: i.e., one needs to know how many of a particular Air Force Specialty (AFS) will be required before one can calculate the training and recruiting burden associated with an emerging system.
- 5) The most direct route to increasing the responsiveness of design to MPT is to subsume Manpower under R&M, providing Manpower-by-AFS estimates in addition to R&M when evaluating the status of a design effort.

Results of individual analysis topics undertaken as part of the Phase I effort have been integrated into the general framework of this report, which was essentially built around two of the Phase I survey and analysis tasks (Task 1, Define tentative integrated system architecture and major functions; and task 4, Relationship between logistics issues and manpower-by-AFS). Issues under Phase I, Task 3 (Task analysis as simulation script) and Task 8 (Feasibility of automated training and technical order generation) were deemed, respectively, too irrelevant and too ambitious for incorporation in the Phase II demonstration workstation development effort. Relevant findings from these and the other topical surveys and analyses have been integrated into the general scheme of this report.

II. ANALYSIS OF CURRENT MANPOWER, PERSONNEL AND TRAINING DESIGN PRACTICE.

Statement of the Problem

The Manpower, Personnel, and Training (MPT) profile for a currently fielded system or fleet may not be optimal when applied to an emerging weapon system. Adjustments to the predecessor system MPT profile or to the emerging system can produce a better match between the field support setup and the emerging system, producing a more supportable system. Limiting

these beneficial adjustments is a design analysis process that does not evaluate the R&M profile of the emerging system directly against maintenance slots within a maintenance environment, but rather against R&M design goals set early in the acquisition process before much of the design work is undertaken. This exigency is due to the lack of analytical approaches and tools for this evaluation. The focus of the proposed effort is to develop and validate an integrated logistics analysis system to evaluate the MPT profile and Reliability and Maintainability (R&M) characteristics of a new system. To describe the approach, the management and technical requirements of the design process must first be explained.

The Design of Large Systems

In the past, aircraft were designed by individuals. One person could do everything required: select an engine; design a fuselage, add wings, empennage, and landing gear; perform stress analysis; and start cutting metal. However, advances in aircraft materials, aerodynamics, and electronics resulted in the modern design team, numbering in the thousands, to develop a modern military aircraft. Some overall strategy to coordinate the efforts of these engineers was clearly needed. The military, after its experience with large system design problems during World War II and the post-war era, developed the systems engineering concept in the 1950's to manage the development of new weapon systems. The basic notions of extended attention to requirements and close regulation of design data development have proven largely successful but increasingly expensive over the past 40 years.

Systems Engineering

Engineering is the act of devising and selecting among alternative approaches to accomplish some fixed purpose. It is little different with large engineering projects, such as developing a new aircraft, except that a great deal of additional attention needs to be paid to management, communication, and documentation. The fundamental concept of systems engineering is to repeatedly divide the design problem into increasingly smaller pieces, design the smaller pieces, then assemble them into the complete design. The systems engineering process occurs according to the following five phases:

Develop Functional Description

The system functionality is determined by developing candidate strategies to fulfill some set of mission requirements. For example, an Air Force requirement may be to attack an air base 100 km behind the enemy's forward position. Two candidate functional descriptions may be for (a) an aircraft capable of carrying a sufficient payload at high speed without being detected by radar or (b) an unmanned cruise missile. Competing candidate functional descriptions are evaluated and a final functional concept for a weapon system is selected and fully developed. The functional description contains system performance parameters that serve as goals or constraints for system performance: MPT issues are usually presented as manpower slots per aircraft, support environment constraints, and R&M system goals. It is this system description, with some description of technological solutions to critical design points, that provides the basis for the Milestone 0 decision.

Assign Functional Allocation

The weapon system functionality is apportioned into subsystem capabilities. For example, the functional requirements of system payload, range, and speed are broken down into engine thrust, gross airframe weight, weapon system delivery capacity, landing gear load requirements, fuel system requirements, and so on. This functional allocation process is performed down to a level where either existing components to suit the function can be identified or the component that needs to be developed can be specified in terms of its technology, size, risk, cost, logistics burden, and so on. The resultant detailed, decomposed system functional description is intended to give

management a clear notion of how the final product will behave. Allocated issues in MPT are restricted to R&M parameters; manpower slots per aircraft are normally not allocated down to particular constituent systems. The result of this process -- the allocated system functional baseline -- is the subject of the Preliminary Design Review (PDR) early in the demonstration/validation acquisition phase.

Design and Integrate Subsystems

The system functional descriptions are translated into hardware designs, e.g., an oleo strut is identified or designed to absorb the projected landing gear loads. MPT issues are still of the R&M variety, with system considerations now calculable from the predicted R&M characteristics and support environment considerations. The design baseline system is reviewed at the Critical Design Review (CDR) prior to fabrication. The subsystems are fabricated and the system is assembled.

Evaluate System Performance

The ability of the system to perform its required function is tested. MPT is computed using measured R&M characteristics and field maintenance concepts data.

Reconsider System Specification

The functional requirements are continually reviewed throughout the weapon system's development process and field life because of changes to the mission requirements, the threat, and available technology. This ongoing, continual review process occasionally leads to the cancellation of an effort or a significant redefinition of the mission. For example, the B1 started life in the 1960s as a high altitude strategic bomber. Its design was later adapted to a low level mission because of improved Soviet defense prior to its entering a production program. This led to reduced capabilities and reliability.

Systems engineering is continually being improved. Concurrent Engineering (CE) has recently emerged as a catch-all phrase for the automated management of system information during the design process. CE is intended to provide a flexible means of accommodating changes and updates to functional requirements and design parameters which have system-wide impact. The motivation for CE is to provide the contractor the means to manage their design data and respond to government data reporting requirements without delay to the designers in their primary work.

Logistics

Logistics is the branch of military science dealing with planning, implementing, and managing personnel, materiel, facilities, and related issues. Modern logistics relies heavily upon mathematical models and analysis of historical data to predict and allocate resources supporting emerging and fielded systems. This activity, termed logistics analysis, is used extensively to predict resource requirements during system development, which is our present concern.

Logistics analysis has two purposes. The first is to propose and evaluate specific design choices affecting the logistics requirements of the emerging system. This is the earliest purpose of logistics analysis and often consists simply of ranking design alternatives on a logistics criterion such as manpower, transportability, or other measure appropriate to the choices at hand. The subsequent purpose of logistics analysis is detailed planning for logistics support of the emerging system.

Figure 1, from AFLC Pamphlet 800-17, illustrates these two purposes of logistics analysis against the phases of the acquisition process. The significant changes in the system design are in the levels of design detail that exist at subsequent phases of the process. A corresponding increase in the level of detail and certainty of logistics support requirements also occurs as the design matures. During the pre-concept phase, in theory if not in practice, the logistician provides information about previous logistics experience with systems similar to ones that might provide solutions to the effort's capability requirement. Later, the logistician provides feedback about subsystems based both upon previous experience with similar systems and analyses of the emerging design. Finally, the design having been finalized, the logistician analyzes the emerging design exclusively (the R&M parameters of which are still based upon experience with previous systems, through reliability and maintenance task time analyses) and turns the use of his analyses exclusively to the planning function. The important thing to note is that the logistician needs flexible analyses. They must be responsive to the broad range of alternatives generated and evaluated early in the development cycle, while they must provide accuracy above all else later in the program.

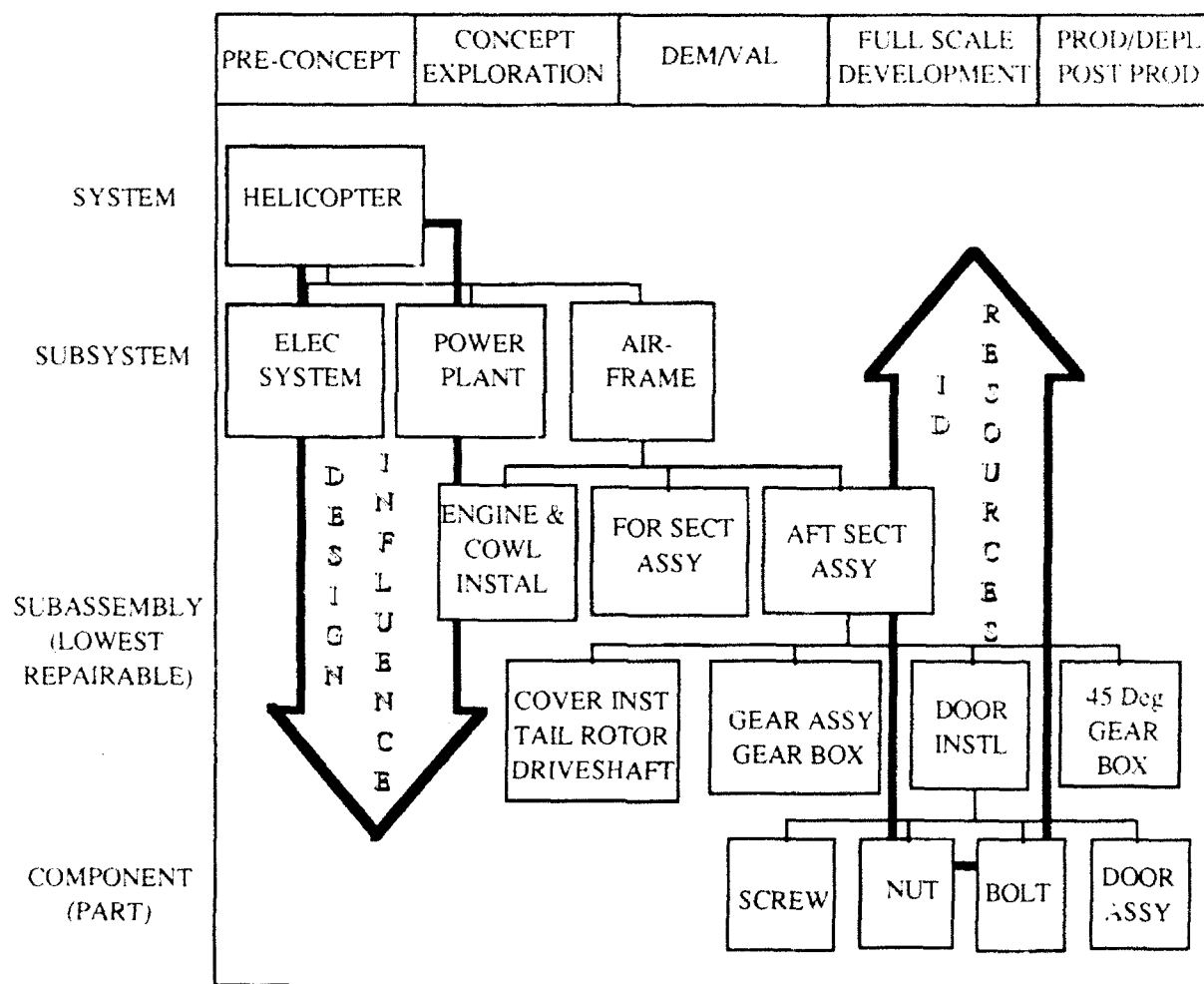


Figure 1
Role of Logistics in the Acquisition Process.

The Role of Logistics Analysis in the Technical Design Process

Aircraft supportability is determined by a complex interaction of equipment reliability, maintenance requirements, AFS and maintenance organization structures, training requirements, and the personnel system. Consideration of these issues is currently the responsibility of numerous logistics specialties. Interaction among these specialties is accomplished sequentially, as some of the specialties depend upon the output of the analyses of others for input to their particular analysis. The entire process is repeated a number of times--at least once per phase of the acquisition cycle -- with the feedback from previous iterations and more fundamental analyses within the same cycle providing input for each analysis activity.

Figure 2 portrays the data dependencies within a single cycle of the design process. The heavily shaded boxes represent the specialties that are active in the earliest phases: Design reviews, task analysis, technical order development, and instructional system development tasks are active only in the final stages of system development.

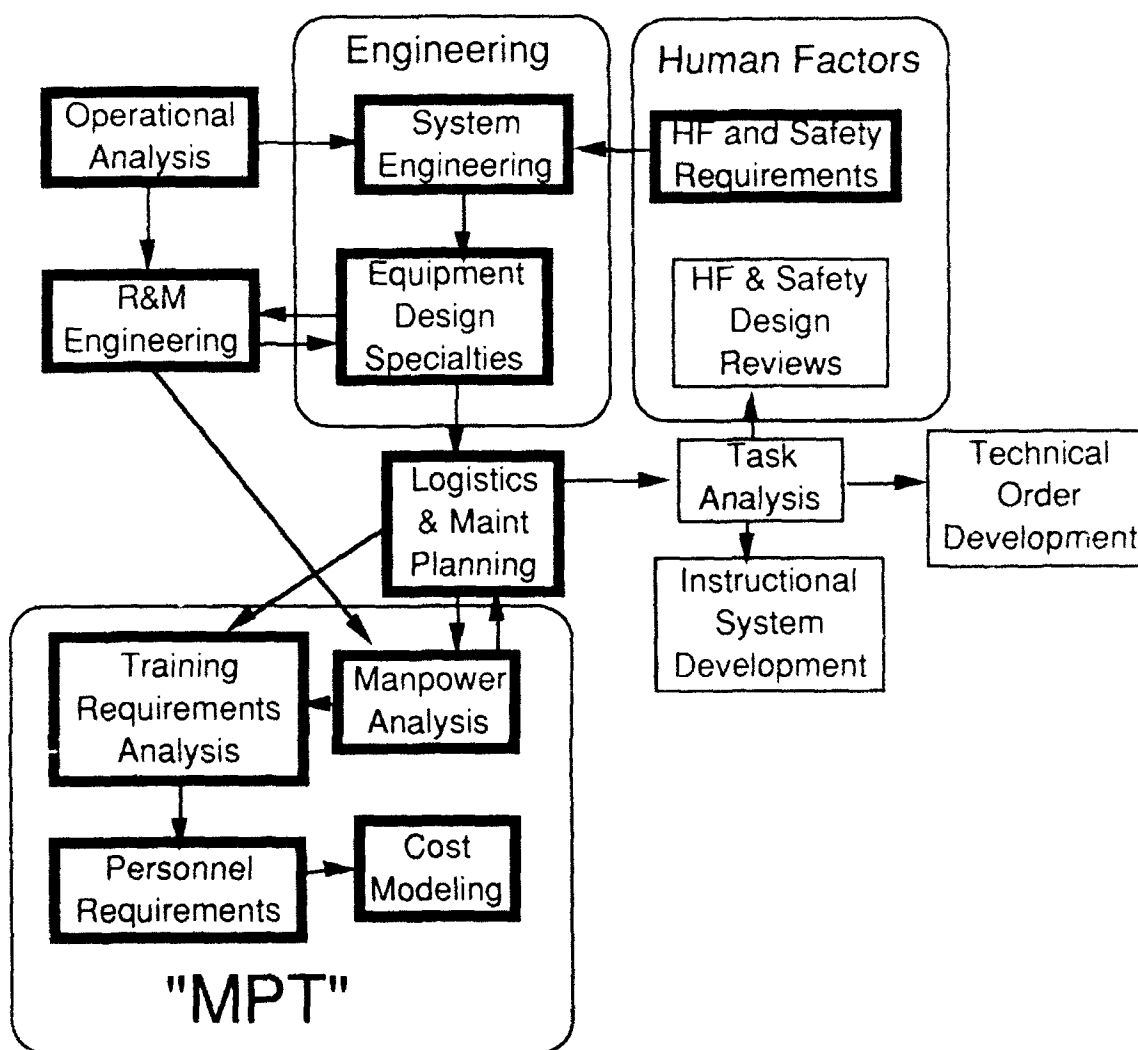


Figure 2
Logistics Specialties Data Dependencies.

Operational Requirements. The fundamental source of system design parameters and concomitant support requirements is operational analysis. Meeting the mission requirements is the primary concern of a weapon system development program. In addition to primary design characteristics such as payload, speed, range, etc., much of the logistics support requirement is generated by the general concept chosen to fulfill the mission requirement. The operational requirements immediately set reliability constraints for systems deemed critical to successful sorties. Additional reliability constraints, and maintenance time constraints as well, are determined by the operational requirements in that the time available to maintenance between sorties is constrained by sortie rate and duration requirements. The process of determining both the physical layout and the sortie requirements is a pliant process involving interaction among the user, the acquiring organization, and contractors in determining whether advances in the state of the art, shifts in the perceived threat, and political conditions are amenable to proposing a new start. Often, these forces will produce logistics goals such as direct maintenance slots per aircraft or maintenance concept; these logistics goals are not always justified by hard analyses.

Engineering. SE and the equipment design specialties (e.g., avionics, propulsion, flight controls, etc.) develop and manage the system design and performance parameters during system development. In the past, logistics performance specifications and expectations were aggregated via systems engineering along with the system's performance parameters. These functions are now delegated to the logistics community in Air Force acquisitions, allegedly because logistics issues were shortchanged by the engineering community. The recent emergence of CE, with its concern for centralized coordination of a development effort and, particularly, its concern for data exchange standards, is an attempt to reintegrate the equipment and logistics areas under a common management umbrella.

R&M Engineering. Also called Supportability Engineering, R&M engineering is the specialty within the individual engineering disciplines that deals with predicting failure rates and with maintenance planning to repair or avert these failures. R&M engineering provides a useful qualitative distinction within its domain to describe the nature of its data at any point. The earliest data, "Comparability" data, are the baseline comparability system (BCS) estimates about the R&M profile on the emerging system. These estimates are obtained by adapting an existing system, or developing a composite of several systems, as a best guess of how the system will perform in the field. The adjustments are performed by subject matter experts and represent the impact of technologies that have become available since the parent baseline system's parent system was fielded. The BCS parameters are gradually transformed into "Allocated" R&M parameters as the functional allocation proceeds, culminating in the R&M profile for the baseline functional system (BFS). This process allows a more accurate R&M estimate than the BCS because the greater detail affords more opportunities to incorporate technology demonstration data. Development of a baseline physical system (BPS) allows the development of "Predicted" R&M data. These parameters are predictions about the implemented design based on field data, reliability models, and maintenance task time estimates.

There are a number of distinct, but related, activities comprising R&M. Failure Modes, Effects, and Criticality Analysis (FMECA) identifies possible failures and their associated consequences in equipment performance. FMECA can be performed on the BFS or BPS. Reliability Prediction, the heart of reliability engineering, predicts failure rates for components of sets of components. The level of specificity for reliability prediction ranges from major systems (e.g., communications avionics, propulsion system)—generally performed by comparison with fielded systems—to additive approaches dealing with aggregation and evaluation of sets of individual components (e.g., capacitors, integrated circuits, gears). Between these two extremes is a variety of techniques that combine the direct comparison and computation approaches, often taking into consideration the effects of environment, configuration, heat dissipation, and so on.

Moving more into the domain of maintainability analysis, R&M engineers conduct a "Reliability Centered Maintenance Program." This is the determination of appropriate inspection procedures and intervals, based on FMECA and reliability estimates. The purpose of this analysis is to develop inspection requirements that keep equipment maximally safe and combat-ready with minimum interference of the peacetime flying agenda. The inspection and periodic maintenance systems are said to be subject to "Scheduled maintenance," while other systems, including the redundant systems, are subject to "unscheduled maintenance."

The R&M profile of an emerging system is constrained by the requirements reliability in two ways. First, to ensure the aircraft can successfully meet its mission, some low level of mission aborts due to mechanical failure is included in the design goals. From the mission profile and acceptable failure rate, minimum reliability requirements are computed for the mission critical systems. This reliability drives much of the maintenance demand, greatly affecting maintenance concept. Second, since the average intersortie unscheduled maintenance time requirements obviously cannot exceed the time available for maintenance between sorties, system design constraints are developed from the mission scenario to limit intersortie maintenance. These constraints are the availability requirements, which are all some variation of the product of failure rate and average maintenance time, divided by the time between sorties. Those critical systems that do not exhibit wear but rather fail randomly—mainly electronics—are installed redundantly if their continuous function is critical to safety; this affects overall system reliability. The unscheduled maintenance R&M constraint is budgeted against these availability goals in developing the R&M profile for the emerging system. Maintenance planning elaborates this maintenance taxonomy by further distinguishing between on- and off-equipment maintenance. This distinguishes between maintenance that inhibits the preparation of the aircraft for further sorties (on-equipment) and that which does not prohibit further use (off-equipment).

Level of Repair Analysis determines where components and subsystems are repaired. The exigencies required to produce high sortie rates currently constrain on-equipment unscheduled maintenance to fault isolation and component replacement (although not always in that order). This reduces the problem to determining on-base versus off-base component repair. On-base component repair generally is implemented around large, expensive, temperamental, general-purpose test equipment; that is, the on- versus off-base component repair question is asked at a high level, early in the system maintenance concept development. The problem centers on test equipment cost versus additional sparing requirements. Task time estimation is performed on maintenance tasks using either comparability or industrial engineering task time computation methods. On-equipment tasks, the critical element in maintaining a high sortie rate, are generally comparability-based design requirements with the onus of a maintenance demonstration to guarantee the design will meet these requirements.

Resource requirement calculations within the R&M community outlined above are, strange to tell, largely delegated to other logistic specialties. Sparing is its own unique province. The current methodology for spares determination is a multiechelon probabilistic model called "DYNA-METRIC." A fixed percentage of stock shortages is allowed in the overall maintenance scenario (referred to as not-mission-capable supply (NMCS) status) and the achieved availability is the potential availability minus this amount. The acceptable shortage rate, along with shipping times, permits calculation of the spares level required at the various supply locations defined for the system. The provisioning community also brings to the task a great deal of knowledge about such things as contracting for spares, sparing requirements across the lifetime of a system, experience with similar spare parts, and the national stick numbering scheme. Calculation of support equipment requirements is similar, albeit simpler. Some portion of the not-mission-capable maintenance (NMCM) time—another percentage used to translate potential availability to actual availability—is allocated to support equipment, and the support equipment requirements is calculated for the scenario. Again, support equipment is a separate specialty within logistics.

Manpower, which will be discussed in greater detail later, is calculated by the manpower community against the maintenance scenario. This service has generally been performed using the BCS data by the manpower shop within the acquiring command. The methodology is a combination of a Monte Carlo simulation (primarily for on-equipment maintenance—typically 70 percent of a tactical wing's manning) and workload or workforce-based standards for many ancillary function (e.g., management, precision measuring equipment laboratory (PMEL), training management, supply, etc.). It is important to note that the resource requirement calculation process requires information about the maintenance scenario and operational requirements, and that all this information passes through the R&M community on its way to the responsible organization.

Of particular interest is the way maintenance demand is measured within the R&M community. Maintenance requirements are reported as maintenance man-hours per flight hour (MMH/FH), broken down by system and maintenance type. Some difficulty exists with this metric. The translation from system maintenance requirements to AFS man-hours is not generated as part of the systems engineering process because this process deals with hardware, not actions. Thus, this translation is not directly available. Worse, accurate translation of MMH/FH to maintenance slots is not easily performed. The current translation method is cumbersome--prohibiting extensive and readily performed alternative analysis.

Maintenance Planning. The independence of the "logistics and maintenance planning" activity in Figure 2 is somewhat misleading. This planning deals with R&M and operational requirements data, as does R&M, but includes the maintenance organization (i.e., which AFS does the work and how maintenance is organized). The important data exchanges within logistics analysis are maintenance requirements and times (from maintenance and logistics planning to manpower analysis) and manpower-by-AFS estimated (to logistic planning activities that require head counts such as training, personnel, and facilities).

Determining the AFSs responsible for maintaining the various subsystems is hampered by the existence of incompatible nomenclatures within the acquisition activity. The systems engineering process assigns a hierarchical identifier to each system as its separate existence is required by the design process. Below a certain level of detail this identifier becomes a unique nomenclature system for the emerging weapon system. This identifier is termed the configuration control number. Beyond this, Logistics Support Analysis Record (LSAR) data require a unique identifier for each of its subsystems and each task and resource associated with that subsystem. These IDs are also unique, with interrelations handled by cross-reference. Although spaces are provided on the LSAR C record for work unit codes (WUCs) and the responsible AFSs, they are not used. Task identification is just as tortuous. The contractor will typically employ a work breakdown structure of his or her own design to perform task analysis and then develop a WUC mapping for the system's tasks to translate tasks into the WUCs. Also, items common to several systems require a national stock number and receive a contractor specific part identifier, which is not compatible with the national stock number. The upshot of this is that there is no simple data connection among part identifiers, task identifiers, and technician identifiers for a weapon system. This is a major hindrance to logistics analysis, not to mention the entire planning function. An early identification of WUC and specialists associated with each subsystem entity would save untold man-hours currently spent cross-referencing data during logistics analysis. Moreover, changes to the system concept that affect manpower or any of the logistics issues requiring the manpower-by-AFS statistic cannot be readily assessed without some sort of way to translate hardware or operational changes into WUCs and AFS responsibilities. Data elements exist in the current LSAR definition to carry the alternative designators, but they also are not actually used.

The current manpower estimation procedure generates a high-level comparability data base using WUCs and AFSs to support a simulation study using the Logistics Composite Model (LCOM). This study estimates manpower for the initial, system-level R&M and operational requirement specifications. These data exist during the BCS manpower study and are then

abandoned, or more precisely, remain at the BCS level within the idiosyncratic LCOM data framework. This is another case of incompatible designators within the acquisition activity. Subsequent design data are not subsequently translated to LSAR for use during system development. These AFS/WUC data are the foundation for the Training and Personnel Data Center (TPDC) Crosswalk program. The cross-reference requirement has been identified numerous times in the past. The initial reference identified as part of the current effort is the Coordinated Human Resources Technology (CHRT) program, which dates back to the 1970s.

Automation may also help the nomenclature problem. The introduction of relational data base notions to the LSAR world with the release of Military Standard (MIL-STD) 1388-2B (Department of Defense [DoD], 1991) may raise the issue of conflicting nomenclatures within the logistics community. Nobody is really interested in an LSAR control number for its own sake: The R&M community is interested in subsystem names, part numbers, and WUCs; the manpower and personnel community is interested in manpower-by-AFS; supply provisioners are interested in the national stock number, etc. Currently, individual user communities are served from the LSAR via Logistics Support Analysis (LSA) reports. The least intrinsically useful information on these various reports are the LSA control numbers. The relational data base format, along with increased computer use by practitioners of the various logistics callings, will encourage direct use of the data base itself to tailor and generate specific reports. As the individual logistic communities will expect to deal with their customary indexing schemes, we should see increased demand for data that can be accessed by means other than the LSAR control number.

A second problem is the translation of AFS workload into manpower-by-AFS estimates. This has been a source of concern since the 1950s. The heart of the problem is that manning needs to be responsible to the maintenance demand distribution, not to average demand. No single good solution exists, although an LCOM-based approach, run early in the acquisition to "validate" the R&M parameters, has been dominant for the last two decades. Strangely, the trade-off here is not between computational ease and accuracy. Manpower estimates made very early can be no more accurate than the very early subsystem R&M estimates and maintenance plans upon which they are based. For a new design, this data is not always reliable. Moreover, a competent LCOM-based study requires many man-months of effort. The status quo manpower estimation situation can thus be characterized as a semiaccurate estimate made with great difficulty. This has resulted in a process where manpower does not directly enter into the design trade-offs.

Human Factors and Safety

HF and Safety are closely related. Within academic human factors, safety is viewed as a subdiscipline; industrial engineering considers safety and human factors distinct subdisciplines with overlapping curricula. However, the Air Force has separate offices responsible for human factors and safety (and, perhaps more critically, requires separate paperwork for each). Consequently defense contractors usually maintain separate organizations for human factors and safety, which frequently overlap. This close relationship is because human factors and safety both look at the operation of equipment by human beings, with safety concerned with potential hazards and human factors focusing on all aspects of equipment operability.

Not surprisingly, their methods are similar, especially early in the system development cycle. Early safety analysis is grouped with early HF for the present study in that their approaches to design are similar. Each has a large body of requirements that is levied on an emerging system, and each has some form of "lessons learned" or catalog of previous mistakes that is scrutinized for wisdom and pass to the design activity. A plan is developed to deal with each HF and safety problem identified; safety programs also demand a separate accounting of the safety training for each system. Note that these general and specific items are passed to systems engineering for implementation. The disciplines are then on call to aid the designers in implementing the requirements.

HF is implemented by providing detailed design guidelines to ensure standardized, usable features for the maintenance personnel. As the design progresses, maintenance requirements are identified, then iteratively refined and expanded to culminate in detailed descriptions of the system maintenance requirements that support safety analysis, task time estimation, and the enumeration of requisite skills for each maintenance job classification projected. By and large HF is forced into a reactive posture by the system development process. It provides guidelines for detail work, but then must wait for design to progress before the suitability of the total design can be evaluated. The desirability of this practice depends solely upon how effective the guidelines are.

Both HF and safety perform design evaluations late in the development cycle. HF is more likely to require demonstrations of its requirements, while safety tends to scrutinize task analysis, training, and equipment design without empirical investigation.

The HF domain defines physical layouts (e.g., size, mass, reach and vision limitations, etc.); shape and color conventions for displays, connectors, controls, etc.; and strength requirements for various combinations of configuration, mass, and personal clothing. The purpose of this domain is to limit possible design choices to a range that is within human capabilities to operate. HF does very little to affect the frequency or nature of the tasks required to maintain an aircraft; these issues are determined by the physical characteristics of the hardware and its R&M profiles. There is no link between HF and R&M, except in cases for which the choice of design alternatives is based upon the impossibility of humans performing maintenance on some design alternative.

A great deal of recent interest has focused on the use of advanced computer-aided design (CAD) technology in HF. The central notion is to develop a computerized model of the human and use it to test the emerging design against human capabilities within the CAD environment. There is still a lot of maturation required in this technology, but it shows tremendous potential. From the point of enhancing the status quo HF process, it may permit the development of more accurate design guidelines and permit a proactive dialog with the equipment physical layout activity. The use of this technology to verify task analysis or technical orders by parsing these data and performing the requisite activities is possible, although a better plan might be to use portions of the man-model technology to author detailed task sequences in support of manual task analysis and technical order development.

Manpower

The success of the systems engineering strategy is due to the decomposable nature and clear understanding of the part/whole relationships of the primary engineering parameters. For example, consider weight. A total airframe weight is estimated and budgeted among the subsystems based on experience with similar systems, predictions of weight for subsystems employing new technology, typical weight growth experienced by other development efforts, and so on. As the design is either further functionally allocated or when the hardware design is underway, more accurate subsystem weight estimates become available. If a system is overweight, the impact on system parameters of performance, payload, range, etc., is readily calculated and the decision to accept the discrepancy, trim the allocated weight from other subsystems, or build a slightly larger aircraft can be rationally made. Needless to say, the choice between the preferred option and one of the latter two is also strongly determined by the cost of the redesign effort in manpower and schedule.

The length of the data dependency—from design description to R&M parameters, to manpower, to training, and finally to personnel—affects how well the systems engineering design process works with respect to these issues. The first bottleneck is reliability. Reliability prediction undergoes a quantum precision change in moving from a comparability approach dealing with

subsystems to reliability prediction over the actual design layout. At the point where reliability information from the hard design is available, the cost of compensating redesign is often prohibitive. To compensate for this unavoidable trade-off between detail and flexibility, much support is available for reliability improvement within a given design, and some otherwise unallocated reliability budget is kept available to handle these problems. Thus, assessing the MPT implications of reliability fluctuations is avoided by the advance of reliability engineering within the design specialties.

The reliability profile directly affects the ability of the emerging system to accomplish the sorties or achieve the requisite sortie rate. Therefore, reliability is a hard design constraint. Moreover, the relationships between reliability and spares cost, maintenance concept, MMH/FH, and number of airframes required to fulfill the mission are well-known and readily assessable at any phase of the development effort to provide a good approximation of the impact of a reliability deficit. Because reliability serves as a hard system constraint and, after all, one can always add more manpower, adding an exact MPT calculation may perhaps only add a third significant digit to the cost impact estimates of non-debilitating reliability deficits. Thus, the MPT community is often asked, "What difference does MPT make?"

Missing from this point of view is the ability to assess the impact of deficient or surplus reliability on MPT issues; manpower is fixed by the early manpower study and treated as a fixed attribute of the emerging system. To optimize a system, the ability to calculate the impact of R&M concept or task time changes of each portion of the system is a prerequisite. Thus, a reliability deficit would be compensated for by selecting the portion of the system in which reliability growth would provide the maximum MPT return. Reliability improvement opportunities could be assessed against the same criteria. This requires input from the MPT community which will allow designers to assess the impact of MPT as easily as the impact of spares and other cost drivers are computed. This is a difficult challenge, because MPT is an inherently more complex arena within which to make trade-offs than are reliability or sparing versus maintenance concept decisions.

The reliability-to-MPT bridge is also the point at which changes to the mission requirements impact MPT. Inasmuch as development efforts take more than a decade, the requirements underpinning the entire effort often change over time. Numerous trade-offs exist between the mission requirement and the ultimate characteristics and number of the system being developed. Unfortunately, many changes to mission requirements change the emerging system greatly in ways that affect aircraft logistic requirements. Thus, the entire logistics analysis cycle must begin again with each change to the mission definition. The current acquisition process tends to lockstep the analysis into fixed phases, with feedback from changes to the mission not affecting logistics planning until the next phase. This is another way of saying that logistics analysis depends upon a fixed mission scenario. The length of time between initial system definition and fielding of the system means that much of the early logistics analysis should be concerned with ranking options in ways that make the resultant design and its logistic characteristics flexible to change rather than providing accurate estimates of exact system performance. It is mainly later in the acquisition cycle, when the mission and configuration of the system will not change significantly, that precise estimates are required so support the acquisition of support materials and for MPT planning. Early in the process, knowing that one alternative is favorable to another is often sufficient.

Early Manpower

Early MPT is primarily the estimation of manpower-by-AFS for a weapon system. The manpower-by-AFS statistic may subsequently be used, along with the AFSs' training and career progression information, to calculate system life-cycle cost. Notably, "manpower-by-AFS" is the metric of the MPT community. The manpower-by-AFS statistic is the bridge between the engineering community's MMH/FH and much of the logistics community. This stems from the fact that logistics planning is on a per head rather than a per flight hour basis. Examples of this are training and facilities: While such statistics as "hours of maintenance training per flight hour" or "food service volume per flight hour" are calculable, they would be useless within the training and facilities planning communities. "Training requirements per person" and "meals served per day" are useful statistics to the training and facilities communities, and these figures require manpower-by-AFS in their calculation.

Still, there is no contextual difference among maintenance planning, R&M, and manpower. Maintenance type, times, frequencies, skill requirements, crew size, and equipment requirements are the fundamental data of the manpower estimation process. Clearly, manpower analysis can be performed as part of R&M and maintenance planning.

Late Manpower

There is no "late manpower" within the acquisition cycle because manpower estimates do not routinely change during the cycle. However, the last few years have seen a change in the Department of Defense 5000 series requirements and manpower estimates are now required at Milestones 2 and 3. It is possible that this requirement will motivate the acquisition community to keep some form of direct manpower estimation data base active throughout the acquisition cycle. This is not currently done.

Training

Training planning, occurring at the earliest phases of system development, deals with determining training requirements to meet personnel requirements and addresses the particulars of transition training to ensure maintenance readiness for the new system when it is fielded. When new training requirements are generated by the new system, these requirements are documented and planning is instituted to include the new material in the existing training courses.

Early Resource Quantification

The number of recruits going through the various maintenance curricula is currently tracked. Consideration of training within the acquisition cycle currently identifies the impact of the new system on the training activity and identifies the number of personnel required to form a training cadre for maintenance and operations (i.e., aircrew training).

Training Course Development

Training curriculum is developed and maintained according to Air Force Manual 50-2, Instructional System Development (ISD) Process (DAF, 1986). This is a systems approach to training which analyzes the requirements and jointly develops training objectives and associated criterion-referenced (mastery) tests. The training courses are reassessed during the final stages of the development process, transitional training is developed, and the initial training courses are adjusted according to the demands of the new system.

Personnel

In the preceding paragraphs, "personnel" refers to the act of determining the number of qualified accessions required to meet the end strength requirements set by the emerging system's schedule and its manpower-by-AFS requirements. Personnel also deals with tailoring enlisted specialties to meet the Air Force enlisted workload. The "AFS structure" is the collection of specialties and associated career paths in which enlisted maintenance personnel participate during their Air Force career.

The personnel system also tracks the career progression of the various AFSs. This entails incorporation of numbers required in the fielded force, training times, and retention data into a model to estimate the recruits necessary to man a new system. As retention rates vary, the force could end up with wrong proportions of senior/intermediate/junior personnel in the maintenance environment. This aspect of the personnel domain is managed by selective reenlistment bonuses, mid-career AFS changes, and early retirements.

A new system is manned by the maintenance structure and organization of the system it replaces. Thus, the personnel community requires manpower-by-AFS estimates for early recruitment planning. The earlier these are available the better because changes to the force population, and to the recruited population, can then be implemented smoothly. To aid this, a ten-year projection of the number of potential recruits in the general population is developed and updated quarterly.

One frequently voiced concern about the status quo of the AFS structure is that it may be over specialized. The drawback of narrow specialization is that, in meeting the peak manning to cover the unscheduled maintenance of a nonuniform sortie schedule, narrow specialties tend to be utilized less fully than a more broadly responsible AFS structure. On the other hand, narrow specialties require less training than broad specialties, resulting in lower overhead because fewer people are in the training pipeline to fulfill future maintainer requirements. The optimal AFS structure balances these two effects (along with other constraints such as availability of facilities and recruit characteristics) to minimize costs while fulfilling the maintenance requirements. The matter of recombining AFSs to form an optimal AFS structure has recently come to the fore. This activity is called "AFS restructuring."

Two different approaches to AFS restructuring—1) the Air Force Armstrong Laboratory Logistics Research Division's Small Unit Maintenance Manpower Analysis (SUMMA) and derivative Specialty Structuring System (S³) projects; and 2) the Rivet Workforce initiative—have occurred within the last five years. SUMMA and S³ developed and extended an analytic framework which breaks down a target system's maintenance workload into homogeneous task groups. These chunks are then clustered into a new AFS structure. Training requirements are calculated by prorating the parent AFS's training requirements against that AFS's portion of the individual task clusters, then applying these prorated training times to the reassembled AFSs based upon the new AFS's task responsibilities. The Rivet Workforce approach was to have subject matter experts restructure AFSs, without quantitative modeling. The Rivet Workforce effort produced a revised aircraft maintenance AFS structure, combining a number of formerly independent AFSs. Given the lack of established analytic approaches in this area, this was not a bad approach.

Another potential adjustment to the existing personnel system is tailoring an AFS structure to particular weapon systems, or "closed looping." The modern Air Force has preferred not to close loop maintenance personnel throughout its history so that the force could adapt easily to a new weapon system and could allow personnel a wider range of career paths. During the period of rapid system obsolescence of the 1950s and 1960s—the era of the century series fighters—this

made a great deal of sense. In the modern era, though, front line systems are expected to remain on-line for longer periods than was formerly possible. This makes tailoring enlisted maintenance career paths to specific aircraft more attractive. Closed looping flightline personnel could support emerging operational concepts--notably single squadron and composite wing deployments--by providing more broadly responsible AFSs without increasing the training overhead for those troops. While some discussion of closed looping and composite wing operations is noted in the literature, no quantitative assessment of the savings possible in manpower, personnel, or training costs for these options was uncovered during the present effort.

"Personnel" also includes the recruiting process. The aptitude of accessions (recruits) is classified by critical subscores from the Armed Services Vocational Aptitude Battery (ASVAB). The recruiting burden is couched in terms of the number and distribution of accessions required for a particular purpose. Personnel models estimate the feasibility and cost of attaining a population of accessions that meet the target number and population. Planning in personnel consists of determining the accession rate to fulfill the maintenance technician requirement, given the training length and success rate, and assuring that the career progression is appropriate in providing appropriate numbers of suitably experienced senior personnel for maintenance supervision later in their careers.

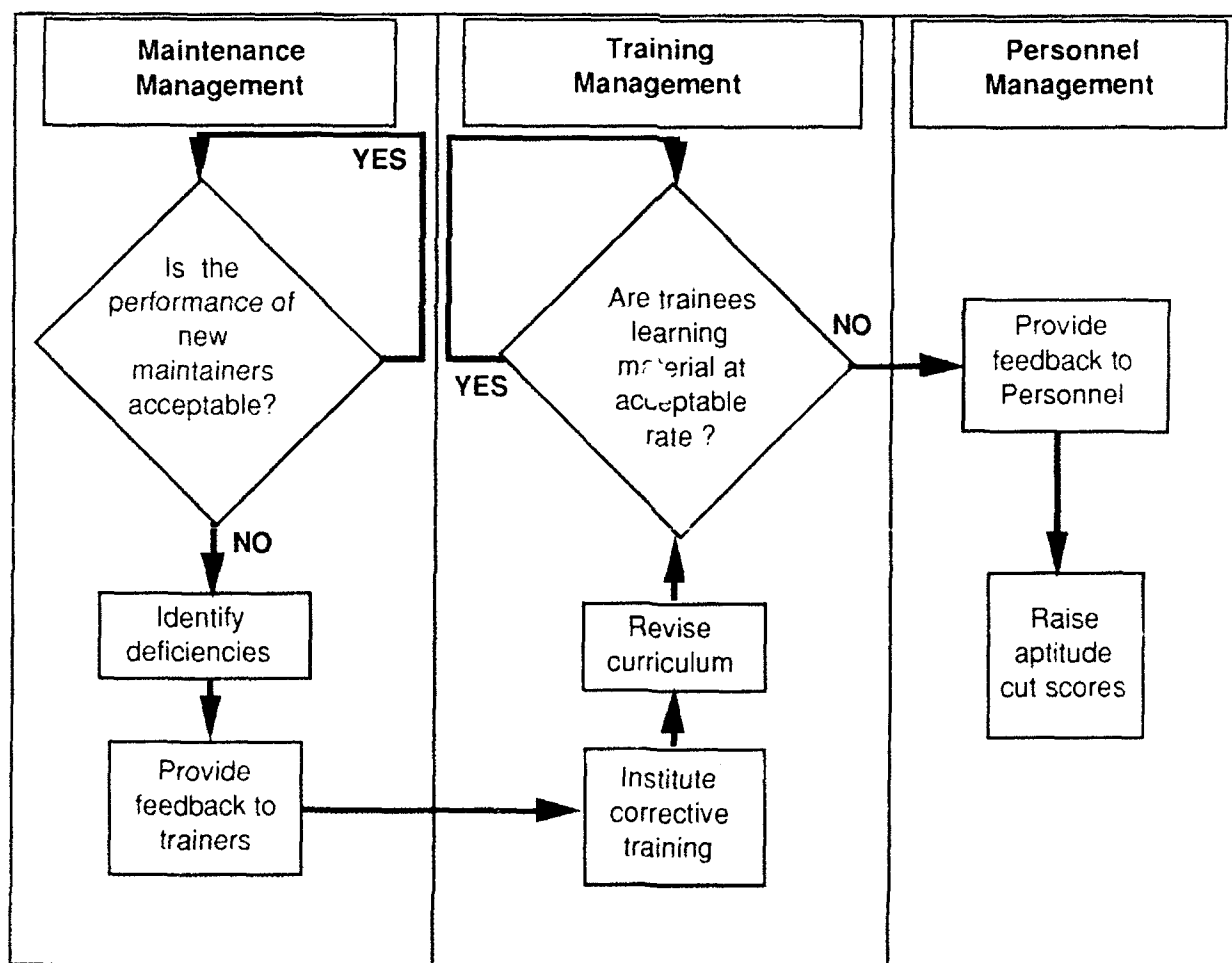


Figure 3
Personnel and Training Feedback Process

Personnel and Training Feedback Processes

Determination and adjustment of personnel aptitude requirements for each AFS is through indirect feedback from field maintenance management through the training process. Figure 3 presents the flow of information in this process. If the performance of new field technicians is deemed unacceptable, the deficiency is reported to the training community for rectification. Two responses are possible; Field Training Detachments may provide supplementary training to personnel in the field or a change in the training school curriculum may be instituted for the affected AFSs. If the course material is not being absorbed by the recruits in an acceptable fashion, training might be restructured or lengthened. The problem might also lead to an adjustment of the minimum ASVAB qualification score requirements. In practice, the actual cut-off score is already higher than the minimum acceptable score for recruits. This was presumably done to exploit a favorable selection ratio.

Thus there is no predictor/criterion data base which directly validates the ASVAB. Rather, the ASVAB employs a content validation approach, with the cutting scores determined experientially rather than psychometrically. Empirical validation of the formal selection instrument is against the training curriculum and training success rates are used for the dependent variable to validate the selection battery.

The lack of data poses a problem for AFS restructuring because analytic paradigms which can be used to evaluate candidate alternative AFS structures require data. First, the minimum cut-off scores are typically lower than the actual cut-off score used, which is determined by selection ratio—the ratio of the applicants available to the recruits needed. Second, the demand distribution for AFSs varies, consuming some potential accessions with higher scores by placing them in AFSs for which they are overqualified. Next, if the demand for maintainers is sufficiently strong, marginal recruits are helped through training by extra practice, tutoring, etc. Finally, the qualification feedback system described is not precise enough to distinguish among related AFSs. Thus, ASVAB Electronics subscale standards for all avionics and electronic specialists is around the 80th percentile, with no distinction made among the specialties by the personnel system.

Manpower, Personnel, and Training Integration

The Air Force recently introduced yet another integrated MPT effort, the "Integrated Manpower, Personnel, and Comprehensive Training and Safety" or IMPACTS. It is widely believed that logistics was integrated and that MPT were two elements of the current scheme of integrated logistics, called "Integrated Logistics Support" or ILS. The major impact of IMPACTS appears to be the generation of an integrated MPT plan that is largely redundant with the existing Integrated Logistics Support Plan (ILSP) but will be read by fewer people. The bureaucratic edifice surrounding this new integration effort will only serve to further separate MPT from its R&M underpinnings in the system design process. This is a giant step in the wrong direction. The Air Force should be moving toward greater integration of the various logistic areas, not toward greater fragmentation. This is the point of recent concepts such as CE and the Computer-aided Acquisition and Logistics Support (CALS) initiative.

Historical Perspective

Integrated MPT has been tried before. Initial development of an integrated MPT management concept, the Personnel Subsystem, occurred in the late 1950s. It was developed as part of the then-emerging systems engineering concept and contained MPT, Training Materials Development, HF, and safety. It was overshadowed by development of integrated logistics in the early 1960s, and, admittedly, lacked a suitable array of tools to integrate its special issues with system design. The next MPT integration effort, CHRT, was devoted to developing suitable tools to incorporate MPT, Training Materials Development, HF, and safety into the design process.

CHRT culminated in a series of underwhelming demonstrations of its methodologies (e.g., Askren, et al., 1976). The basic concepts of CHRT were picked up by the Navy as their HARDMAN project, the kernel of which still exists as HARDMAN III and IV. The Army and Air Force both expressed interest in HARDMAN; this interest culminated in the Army MANPRINT project in the mid-1980s. By this time, MPT integration had progressed to the higher science of mapping out the acquisition documents and requirements that must be included in a major system acquisition, leaving behind the mundane methodological concerns that plagued earlier MPT integration efforts. The Air Force considered directly adapting MANPRINT, but decided instead to invent their own.

Integrated Manpower, Personnel, and Consolidated Training System

Figure 4 represents the logistic areas relevant to MPTS issues. The abscissa represents the flow of an acquisition process over time; the arrows represent the major flows of information. The enclosed area is the MPTS domain as defined for IMPACTS. The striking feature of this is the exclusion of maintenance planning and R&M. This reinforces the existing distinction among logistic domains and the partitioning of resource estimation activities from those that provide their data sources.

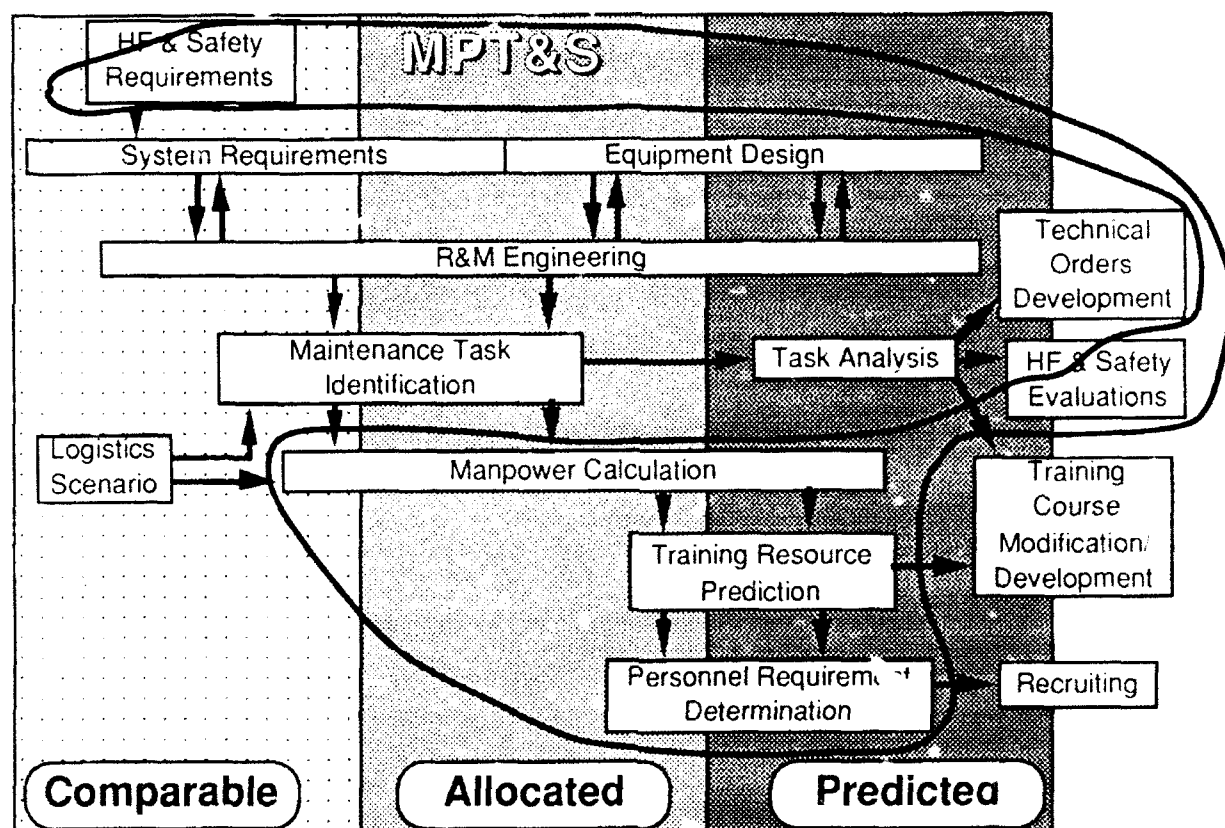


Figure 4
Traditional Integrated MPTS

The question arises, "Integration MPT for what purpose?" The MPT domain is not independent from the R&M and maintenance planning activities; therefore, the answer cannot logically be, "To make the design more responsive to MPTS issues." Imposing a supplementary bureaucratic edifice upon an already unresponsive system is not a good solution to the problem of unresponsiveness. A better solution is to make MPT issues a more integral part of the more

fundamental engineering and logistic domains. This is no longer a management issue or a case of the logistics community being ignored. The Manpower Estimate Report (MER) requirements, even if there were no prospect for increased efficiency, has thrust MPT into the center of the design process. This is now a technology issue: there is no good way to remove the barriers between the logistic domains, and these barriers are the cause of the oft-cited unresponsiveness of design to these issues.

III. AN ALTERNATIVE SCHEME OF LOGISTIC INTEGRATION

Figure 5 presents an alternative scheme to integrated logistics. The larger, shoe-shaped area in the left of the figure is termed the Logistics Resource Requirements activity. It deals with developing early R&M parameters and provides, in addition to the usual R&M metrics, manpower-by-AFS estimates as well as the training and personnel requirements necessary to support the manpower-by-AFS profile. The focus of the proposed effort is to develop a single workstation to address all of these issues. This facility leads eventually to the development of cost estimates based on MPT issues as part of the early R&M activity. The cost estimates become the basis for trade-offs among R&M and MPT factors within the design activity.

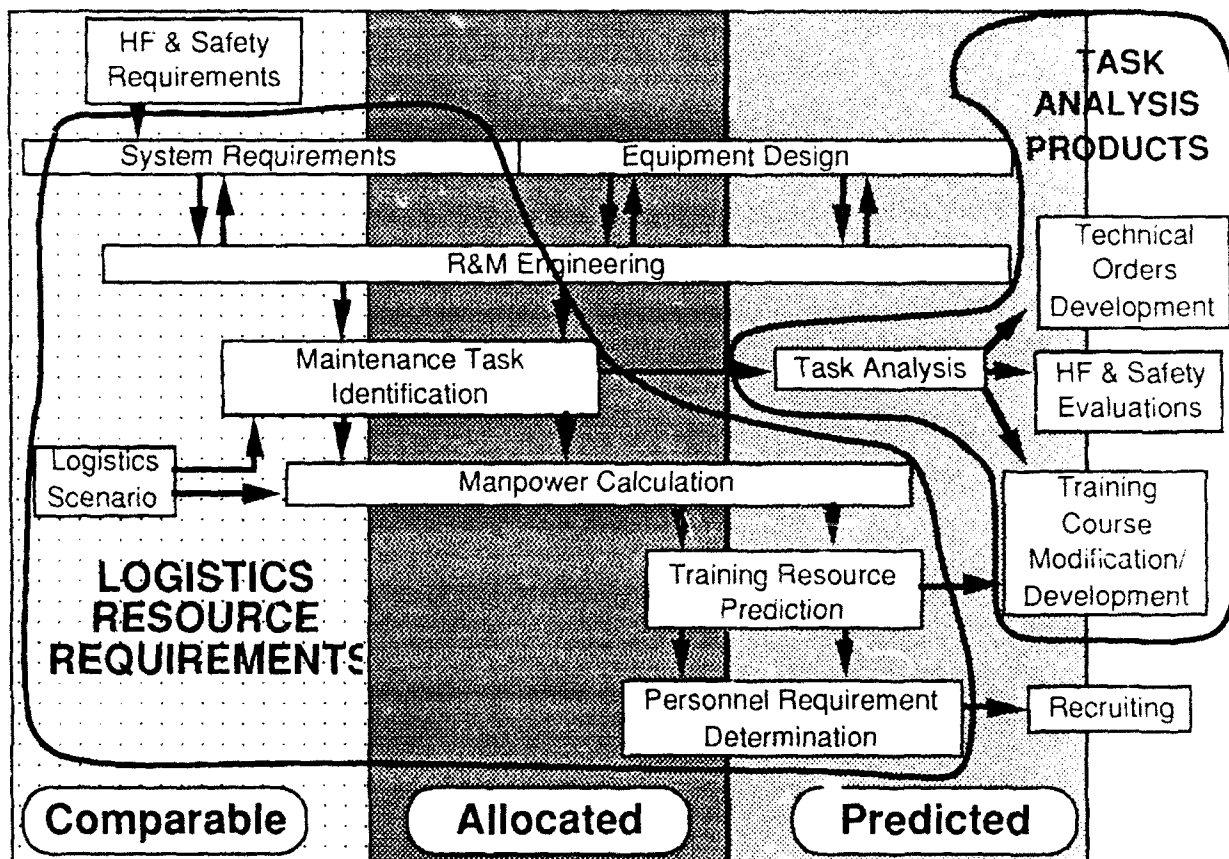


Figure 5
Alternative Grouping of Logistic Domains

HF and safety are removed from MPT: both HF and MPT are unaffected by this change because the domains do not overlap. Since the integration scheme proposed for this effort is an integrated logistics analysis tool and the data base is an extension of LSAR, comparability and allocation portions of R&M are co-opted within the Logistics Resource Requirements activity. The

goal is to produce an R&M management data base interface for R&M purposes and integrate this with the other maintenance planning and MPT issues. The change in R&M is that maintenance manpower-by-AFS and MPT cost statistics will be included in the R&M reports.

Not shown in Figure 5 is a new data link between the maintenance task identification and the two training boxes. The integration proposed here is between the training objectives in ISD and the tasks that these support. In addition to integrating ISD with LSA, this linkage forms the basis for evaluating alternative AFS structures in light of both manpower-by-AFS and training and personnel burden.

The duck-head shaped area on the right side of the figure is titled the "Integrated Task Analysis Products" section. Combine these activities into a single process would be facilitated by changes to the LSA and ISD processes developed by the proposed effort, although this is outside its scope.

IV. ISSUES IN INTEGRATED MANPOWER, PERSONNEL, AND TRAINING/ RELIABILITY AND MAINTAINABILITY ANALYSIS

Phase II will implement and verify an integrated supportability analysis and trade-off tool. Phase I identifies compensatory relationships among the operational, R&M, and MPT domains, described in detail below. Another portion of this effort is previous work on the relationship between R&M and MPT analyses.

If successful, this effort will demonstrate an integrated logistics resource requirements tool for MPT and R&M issues suitable for use in the systems engineering and logistics communities during system development. The approach will allow the currently unaddressable issues of training impact and AFS structuring to fall under the control of project management during system development. This will provide increased ease and timeliness in evaluating the trade-offs among the logistic and design parameters. Possible follow-on work will include expanding the system to a Class 2 LSAR automation tool as a basis for future services to government and industry.

Top-Down Systems Tool for Logistics Baseline and Modifications

The successfully completed Top-down Systems Tool for Logistics (TDSTL) project is a loosely connected group of three efforts that sought to provide a means to apply systems engineering principles of functional allocation and successive refinement to MPT issues. The first of these efforts produced a process and data model which divides MPT analysis into standard categories and identifies design measures of merit germane to the MPT domain (Miller & Boyle, 1991).

The Integrating Manpower Analysis with Computer-aided Design (IMACAD) effort—the second in this series—developed an approach and software demonstration for allocating and monitoring manpower by AFS during system development in place of the current practice of allocating and monitoring R&M. The advantage of this approach is that, since MMH/FH is a difficult statistic to translate into manpower slots, meaningful trade-offs between R&M and other logistics and operational considerations may be facilitated by looking at the manpower slots directly rather than proxying the measure with maintenance man-hours.

The final TDSTL effort refined the IMACAD software product by streamlining the interfaces and adding work center, mixed mission analysis, sensitivity analysis, indirect labor, and cost analysis facilities to the basic structure. A revised data set, against which these features were validated, was developed and includes these new features. The effort also traces the evolution of F-16 R&M development and documents the disassociation of the manpower requirements from the R&M process.

The manpower calculation scheme has two aspects. First, all direct maintenance work is classed as scheduled or unscheduled and on-equipment or off-equipment, or as indirect labor. On-equipment tasks are also classified by whether they impede the use of the aircraft for a sortie or sortie preparation activity. Second, manpower is calculated for each AFS at each work center in three ways: The largest of these is taken as the manpower estimate. One of the three manpower estimators is to consider the sortie-impeding work (generally, on-equipment work) as a queuing problem against the system availability requirement, with Number of Crews times Average Crew Size times Number of Shifts as the manning (Peak Manning). The second estimate is to man for all the workload against manpower availability and shift policy (Workload Manning). The third method is to man to meet the task with the largest crew size requirement, considering shift policy (Max Crew Manning). This, essentially, handles the LCOM manning which is about 70 percent of a tactical wing complement. Additional manning strategies, based on manning standards, are also available to complement this strategy.

The final software produced acceptably accurate manpower estimates. Interested readers should obtain a copy of the final report (Miller, in press). The data base from that study needs expansion for the current effort. Also, the system still needs development of the user interfaces to support the various communities in the Logistic Resource Requirements domains. Nonetheless, the demonstration showed that Manpower can be integrated with R&M data management and this provides a solid basis for the current effort.

Several improvements in the system are potentially beneficial. The major improvement would be increased ability to manipulate and analyze information at the work center level. This would permit more control over such things as crew composition and shift policy, and would allow work-center-by-work-center manpower analysis—as opposed to analyzing the entire wing or operating location data base—which would permit a more detailed analysis without undue delay in obtaining results.

Manpower, Personnel, and Training Integration Issues

The current approach is to treat MPT as a part of R&M. The interrelationships among MPT issues are complex. Furthermore, data and methods are either unavailable to the acquisition process or nonexistent for many of the potential trade-offs.

This section catalogs MPT data and what is known about relationships among MPT issues. Well-understood relationships are those for which there are models or data that quantitatively explicate MPT resource requirements and, often, the manner in which one resource can compensate for another. For example, the relationship between manpower and maintenance concept is well understood in that the direct maintenance man-hours for various maintenance concepts can be calculated and from this, manpower-by-AFS can be derived. On the other hand, the relationships among AFS structure, training time requirements, and personnel aptitudes are unknown beyond the nonqualitative notion that broader AFSs should require individuals with higher aptitudes and/or longer training times. Also, for the sake of this discussion, details, on-the-job training (OJT), and management tasks are considered part of the maintenance workload.

Well Understood Relationships

- Reliability vs. maintenance demand
- Mission requirements vs. maintenance demand
- Maintenance times vs. maintenance demand
- Maintenance concept vs. maintenance demand
- Maintenance demand vs. maintenance manpower-by-AFS
- Maintenance manpower-by-AFS vs. maintenance task responsibility for each AFS
- Maintenance manpower-by-AFS vs. training requirements
- Maintenance manpower-by-AFS vs. required accessions per year

Ancillary Data to Make Trade-offs Over These Relationships

- Maintenance task demand (reliability) by AFS and work center
- Maintenance task times by maintenance concept
- Details, OJT, and management task requirement by AFS and work center
- Attrition rates per year by AFS
- Career progression steps and times
- Maintenance task responsibility for each AFS
- Training times by AFS
- Variable and fixed costs by year of service for manpower
- Training costs
- Accession costs by AFS requirements
- Other personnel costs

Well understood issues are those that deal with assessing the MPT requirements and costs for a fixed AFS structure (maintenance task responsibility for each AFS). Because of the data assembly and calculation problems discussed above, the most troublesome step is converting R&M, etc., into manpower-by-AFS estimates. The manpower-by-AFS implications of a new AFS structure can also be assessed once task responsibilities are apportioned among the new AFSs. The implementation of a facility to integrate this set of MPT functions with the R&M process was the accomplishment of three previous SEI efforts: IMACAD, TDSTL, and TDSTL II.

Poorly Understood Relationships

- Training times vs. personnel aptitudes by AFS
- Training times vs. maintenance task responsibility for each AFS
- Personnel aptitudes vs. maintenance task responsibility for each AFS
- AFS career progression vs. maintenance task responsibility for each AFS
- Attrition level vs. maintenance task responsibility for each AFS

Ancillary Data to Make Trade-offs Over These Relationships

- Training block required for each maintenance task
- Personnel aptitude requirements by AFS
- Training times by training block
- Training blocks in curriculum by AFS

A clearer view of these poorly understood relationships is necessary to assess the MPT impact of AFS restructuring adequately. Without an adequate understanding of the implications of AFS restructuring on aptitude and training time requirements, a less efficient or even unfeasible AFS structure may be devised.

The major objective of the proposed effort is to develop and validate a methodology for AFS structure optimization within a single weapon system and to estimate the improvement this alternative structure will afford over a more conventionally structured force. This entails addressing these poorly understood relationships.

Training Integration

The central issue in training integration is determining the training requirements for an arbitrarily defined AFS. Acquiring these data seems straightforward. The training curriculum for an arbitrary AFS structure could be readily determined if the training requirements underpinning a system maintenance task were tracked during system development. Curriculum tracking during system development is currently done for safety or for "new" technologies through the current

LSAR G record. Moreover, a complete understanding, on somebody's part, of the entire curriculum/task linking during the acquisition process is implicit in the current LSA process in that the impact of a new design is required by the current LSAR. Data elements exist for new training and personnel skills in the LSAR, but no data elements exist for current training and personnel skills from the predecessor system. Information about the status quo needs to be available at some level to both generate and validate the logistics analyses on training impact; This is necessary because the status quo comprises the baseline against which the decision of whether a maintenance task requires new training or personnel skills needs to be made.

Figure 6 presents the current LSA/training community interface and its proposed revision. The existing interface examines the required maintenance tasks and safety program requirements and produces requirements for safety training. It also identifies where new technology will impact the training of the baseline AFS maintenance technicians. The revised process carries the baseline training block descriptions and develops the links between the tasks and training blocks as part of the baseline data. Reviewing the training-to-task mapping will be unnecessary after the design is specified to the three-digit WUC level, (late in concept exploration) because fine tuning of the subsystem components will not affect which AFS is responsible for them.

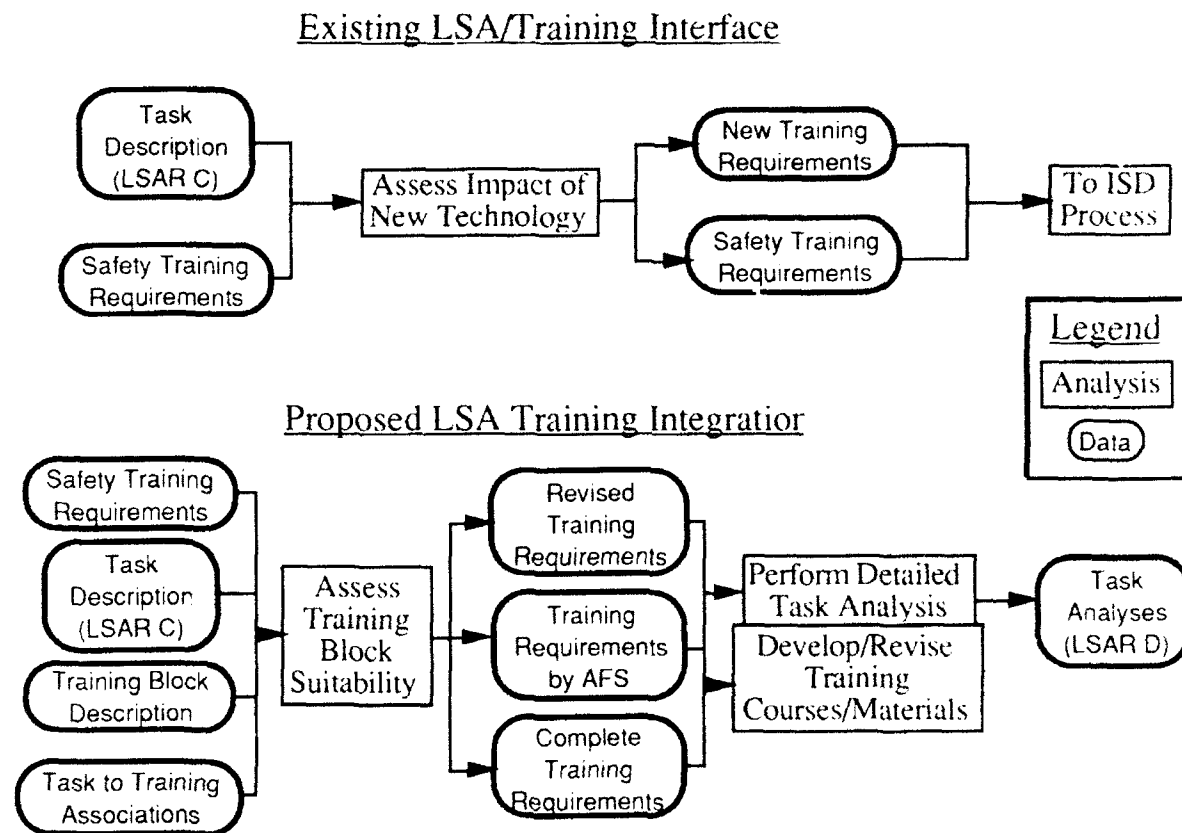


Figure 6
Proposed LSA/Training Integration

The current Instructional System Development (ISD) process produces specific target-behavioral descriptions for each training block. These descriptions should readily support matching training blocks to the LSAR C record task descriptions that they support. Additional

effort inherent in this proposed LSA revision is in maintaining the AFS-to-WUC mapping, mainly due to the nomenclature problem.

An estimate of the impact of a new system upon the training curriculum could become available quite early in the acquisition process. Moreover, the revised behavioral descriptions are then available to the detailed task analysis, which would be integrated with the ISD process in a fashion to be specified—but not developed—during the Phase II effort. The LSA process is enhanced by having an explicit training baseline against which system design particulars might be weighted. The ISD process is enhanced by being integrated with the system design such that the impact of curriculum requirements becomes available in time to influence system design decisions.

The use of LSAR in ISD has been repeatedly suggested in the past, dating back to the 1970s (for example, see Staten & Boyle, 1988). An effort currently under way, the Joint Service ISD/LSAR Decision Support System (DSS) (Sorensen and Park 1990), is developing a system to supply LSAR data (mainly task analysis data) to develop training for a new system. The ISD/LSAR DSS picks up LSAR data at the point where task analysis is complete (generally quite late in the development cycle) and makes no attempt to provide early assessment of the impact of technology on training requirements to the design activity. Thus, follow-ons to the ISD/LSAR DSS can possibly benefit from the proposed early integration of LSA and ISD engendered in this proposed effort.

Overall, this proposed revision develops data that enhance the existing LSA and ISD processes while providing a workable means to assess the impact of AFS structuring. It provides the ability to determine the training requirements for alternative AFSs in a quantitative fashion. This allows AFS restructuring to use training time as a criterion in AFS structure optimization. Alternative approaches have all handled this problem by relying on expert judges to rate the similarity of existing AFSs or maintenance tasks. This proposal represents a dramatic improvement over these alternative approaches by providing a measure of AFS similarity that can be continually evaluated, is objective, and essentially comes as an added benefit of an LSAR data expansion that has a great deal of merit in its own right.

Other Training Relationships

The previous paragraphs present a scheme to develop exact training requirements for arbitrarily defined AFSs to support AFS restructuring, but what is known about the poorly understood relationships between training requirements, training times, and aptitude which may moderate these requirements? Beyond information about the existing AFS structure, the relationship among aptitude, training times, and AFS structure is little understood. This shortcoming is the cost of the personnel and training management strategy that the Air Force has adopted. Thus, although the current system works, and can probably be adjusted to work again for a new system if things don't change significantly, the effects of a drastic change to the AFS structure cannot be predicted. The question is "How can we generalize from information about the current AFS structure to another AFS structure?" If we view the current AFSs as a sample from the larger population of possible AFSs, some answers might be forthcoming.

Aptitude Requirements for New AFSs

How might aptitude requirements for drastically consolidated AFSs be estimated? Estimating aptitude for new AFSs is more problematic than the curriculum issue. Because the Air Force personnel process doesn't follow the accepted empirical predictor/criterion prediction paradigm, a body of information linking aptitude and job content may not be available. Little was uncovered by a review of personnel and training literature on this issue. For example, several studies (for example, Mumford, et al., 1987; Newstad & Schuster, 1982) develop an empirical instrument to predict aptitude requirements for the existing Air Force initial training curriculum.

This is very good work, but it deals with the entire training curricula and is not generalizable to parts or composites of the curricula as would be necessary in an analysis tool designed to restructure the curriculum for an alternative AFS structure.

The nature of the relationship between aptitude and training requirements is further confounded by the relationship between training time and aptitude. If time is unconstrained for a fixed curriculum, the single most difficult block of material would determine the minimal aptitude and background requirement for a training sequence. If training time is held constant at existing levels for each training block, the relationship might be better represented by an additive model, where mastery of each incremental training block requires a bit more aptitude or background than a training curriculum not containing that block.

The actual situation is most likely a mixture of the power and additive effects: a broader AFS structure would probably be best manned by a more capable population; this would allow each training block to be mastered in a shorter period. On the other hand, career training times might need to be increased to accommodate frequent reviews of previously mastered concepts as part of providing students with the substantially larger body of knowledge required to perform the duties of an expanded AFS.

There must certainly be a way to derive credible aptitude estimates for broadly expanded AFSs from data on the existing AFS structure and existing AFS aptitude requirements. Existing data include the curriculum blocks for existing AFSs and their minimal aptitude scores. An examination of these data may answer whether a power or additive model is appropriate and provide a means to estimate aptitude requirements for arbitrarily defined AFSs.

If a nonadditive model is appropriate, some courses common to several AFSs will determine the minimal aptitude scores for these AFSs while other common courses will apparently have no influence. Training blocks would serve as a partially ordered set of aptitude requirement determiners. This relationship among training blocks could be used to remove courses from the set of independent variables within a regression analysis of the data. The problem is to seek out patterns of common training blocks among the AFSs and assemble the dominance order within the data. The degree to which the nonadditive model is appropriate to the data will be estimated by the degree to which these patterns predict the data's aptitude requirements. Situations where data such as

AFS	Training		Aptitude
1:	1	2	X
2:	1		Y

will be identified: where $X=Y$, a dominance relationship exists; otherwise, If $X \geq Y$, training block 2 dominates and if $X \leq Y$, the situation is indeterminate. More complex relationships such as

AFS	Training			Aptitude
1:	1	2	3	X
2:	1	2		Y

indicate joint domination of Training Block 3 by Blocks 1 and 2 where $X=Y$; Training block 3 could be removed from the analysis. Alternatively, in situations where $X \neq Y$ an additive model is more appropriate to the situation. Nondominant courses would have no correlation with aptitude requirements. The existence of nondominant, correlated training blocks suggests an additive model. A regression using individual training blocks as dichotomous predictor variables would have significant weights on only the dominant variables, as these are the only ones related to the criterion (aptitude). The regression model would appear as

$$\text{APTITUDE} = \beta_0 + \beta_1(\text{common block 1}) + \dots + \beta_N(\text{common block N}) + \dots + \beta_{(N+1)}(\text{individual block 1}) + \dots + \beta_{(N+M)}(\text{individual block M}) + e.$$

The use of regression to estimate weights for the additive model has two obvious flaws. First, the model will be overfitted. The obvious solution is to reduce the number of predictors to develop the predictor equation. This approach would produce a simple equation which might well set most AFS aptitude scores to the existing mean. The second problem is that a regression equation would have little meaning. It would obviously have no physical meaning in cases where a training block's weight is negative. It is difficult to imagine a situation where adding a particular training block to a curriculum has the effect of decreasing the average aptitude required to complete the overall curriculum. Just as bad, taking all the training courses within a data base would result in an aptitude estimate equal to the mean of the AFSs contributing to the data base. This situation can be improved upon. Since all the predictor variables are dichotomous, it would be possible to transform the equation by subtracting the value of the most negative weight from both sides of the equation. This would provide a model that has a higher degree of physical meaning in that additional courses placed into a curriculum would always increase the aptitude requirement. This would not solve the overfitting problem.

The approach developed in the Phase II effort would attack the ASVAB requirements problem through separate developments of a regression approach and a nonlinear predictor approach employing neural networks.

Other Personnel Issues

The "Training times vs. Personnel aptitudes by AFS" trade-off may possibly be addressed through training records. The obvious means to attain an estimate of this trade-off is to regress training times against ASVAB scores for a suitably representative sample of training courses. It is unclear if both these personnel-sensitive items are available at one location. One effort reviewing this same problem stated, "The level of aptitude required for successful performance of a task was found to be conceptually inseparable from the time required to learn to perform the task at a satisfactory level" (Burtch et al., 1982). While the present author considers this an overstatement, this analysis would consume a large share of the resources available to the present effort. Thus, training time will not be a variable in the present effort.

Finally, no reference to a study that attempted to correlate AFS attrition level with specific task requirements was found. While a approach similar to that proposed to predict ASVAB requirements could be applied to the attrition problem, it would have little chance of being successful, or even credible, as attrition level is not likely to be closely related to specific tasks within an AFS's purview to the same extent as aptitude is. Moreover, attrition level for individual AFSs vary across locations and time to an extent that little precision is gained beyond the gross averages when using these data. Thus, we will use specific AFS attrition data for comparability purposes and force averages for reconstituted AFSs.

Personnel Management Issues

Analytical support for maintenance organization analysis and career path structuring will be provided in this effort. The trade-offs surrounding these two issues are even cloudier than the "Poorly Understood" relationships above in that the relevant issues cannot be neatly laid out. But these two issues are as vitally related to the feasibility of a new AFS structure as are its training or personnel implications.

Maintenance organization is important. The principle argument put forth to support the development of more general AFSs (i.e., that more broadly responsible AFSs have a steadier

maintenance task demand rate and can be utilized more fully) applies to work centers as well. A larger work center will have a steadier demand rate than a smaller one and thus be able to more fully utilize its maintenance manpower. The trade-off here is between smaller, more specialized shops, which are easier to manage, and larger shops which reduce overall management overhead but become more complicated to manage and communicate within.

If an AFS structure is to succeed, career progression must be taken into account to provide a distribution of suitably experienced journeyman-level maintainers and senior-level supervisors to man the maintenance system. The structuring of work centers is important to gaining the experience to facilitate this career progression. Insofar as the management function relies on familiarity with the tasks performed at a work center, the AFS careers leading to the supervisory AFSs should be exposed to these work centers. Thus, work center structuring is important to developing maintenance efficiency for career development.

Maintenance organization analysis and career path structuring seem well worth exploring in the present effort, and is a relatively untouched arena for MPT integration and automation. However, since the basis for career path determination and work center structuring are unclear, no optimization strategy is apparent at this time. The Phase II effort will develop a means to compute MPT costs for plausible options in these areas and trust the analyst to provide the rationale for the changes.

Implementation Particulars

Data Base Design

Figures 7 and 8 present the proposed data schema for the effort. Figure 7 contains files that are primarily designed to store input data describing the aircraft, mission, and maintenance particulars; Figure 8 is devoted to files of the system's analysis results. Necessary links to the LSAR, equivalent LSAR Control Numbers, stock numbers, etc., are not included because they are not necessary parts of the proposed analysis system although they will be developed as part of the effort. A short study of the figures will complement the following discussion. Each rectangle represents a data table, with its name at the top, separated from the table elements. The data tables with the word "join" in the title serve to associate the system's major constructs, but are of little interest. Table elements ending in "ID" are internal identifiers for each entity. The major data constructs are:

- maintenance concepts
- AFSs
- work centers and bases
- missions and sorties
- aircraft
- systems and WUCs.

A maintenance concept is a collection of WUCs each joined to an AFS, a work center, and a description of the task in the WORK_DESCRIPT table. One data base can store several competing maintenance concepts for a given base, aircraft, and mission model. The task class (TMAINT) classifies the task into on-equipment, off-equipment, scheduled, unscheduled, indirect, etc., types of maintenance. The additional parameters describing the task are the proportion of the time this AFS performs that task (PERC), the length and frequency of the task (LENGTH and DEMAND) and the average and maximum crew size requirements.

A WUC is a task. It is given a name (GNAME) and is associated with training and with particular subsystems on the aircraft. It is also associated with a description in the TASK_DESCRIPTIONS table. These are essentially the LSAR C Record task descriptions.

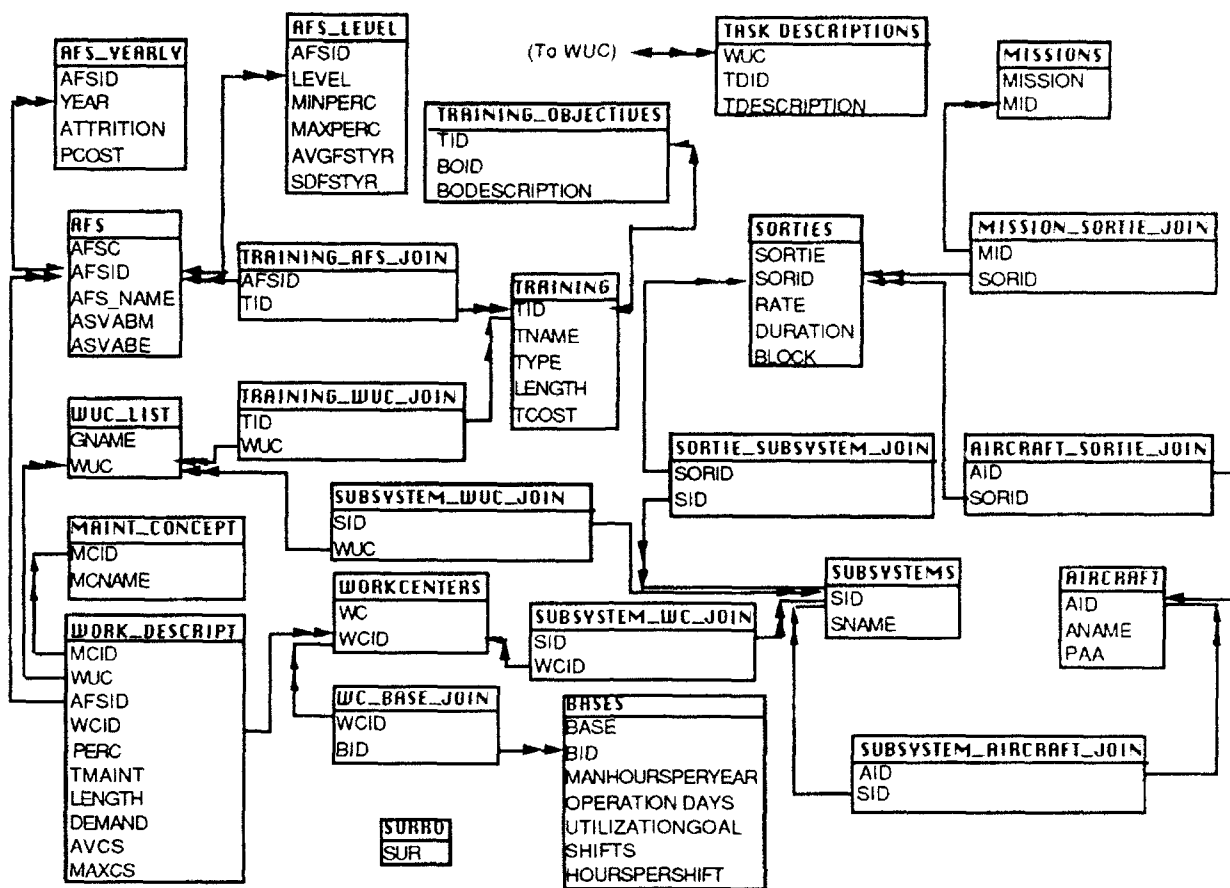


Figure 7
Scenario Data Schema

An AFS is an Air Force job within a career field. The AFS table contains the AFS name and the mechanical and electronics ASVAB minimum scores. An AFS is associated with attrition and skill-level in the AFS_YEARLY and AFS_LEVEL tables. An AFS is associated with its training curriculum and task assignments through the TRAINING (via the TRAINING_AFS_JOIN table) and the WORK_DESCRIPT tables.

A work center is a location where work is performed. A base is a collection of work centers. A base contains several parameters relating to personnel availability and operating days per year.

A sortie is defined by the rate, duration, and number of aircraft involved (BLOCK). A mission is the aggregation of sorties flown by the aircraft in the model. The mission provides the impetus for maintenance actions in defining how much each aircraft type in the model is used and, hence, the maintenance demand for its constituent systems. Note that there is no inherent constraint to the number of different aircraft types that can be defined in the model.

An aircraft is associated with a name and a primary aircraft authorization (PAA) in the AIRCRAFT table. Aircraft are collections of systems. A system corresponds to the entities documented on individual LSAR B records, at whatever level of indenture is convenient, but is associated with its R&M tasks indirectly through WUCs. This follows LSAR logic in that the R&M data are on the C and D records rather than the B record. Systems can also be associated

with individual sorties to model sortie-specific systems or handling, and with work centers to model support equipment maintenance and indirect duties associated with work center or base support, training, and management tasks.

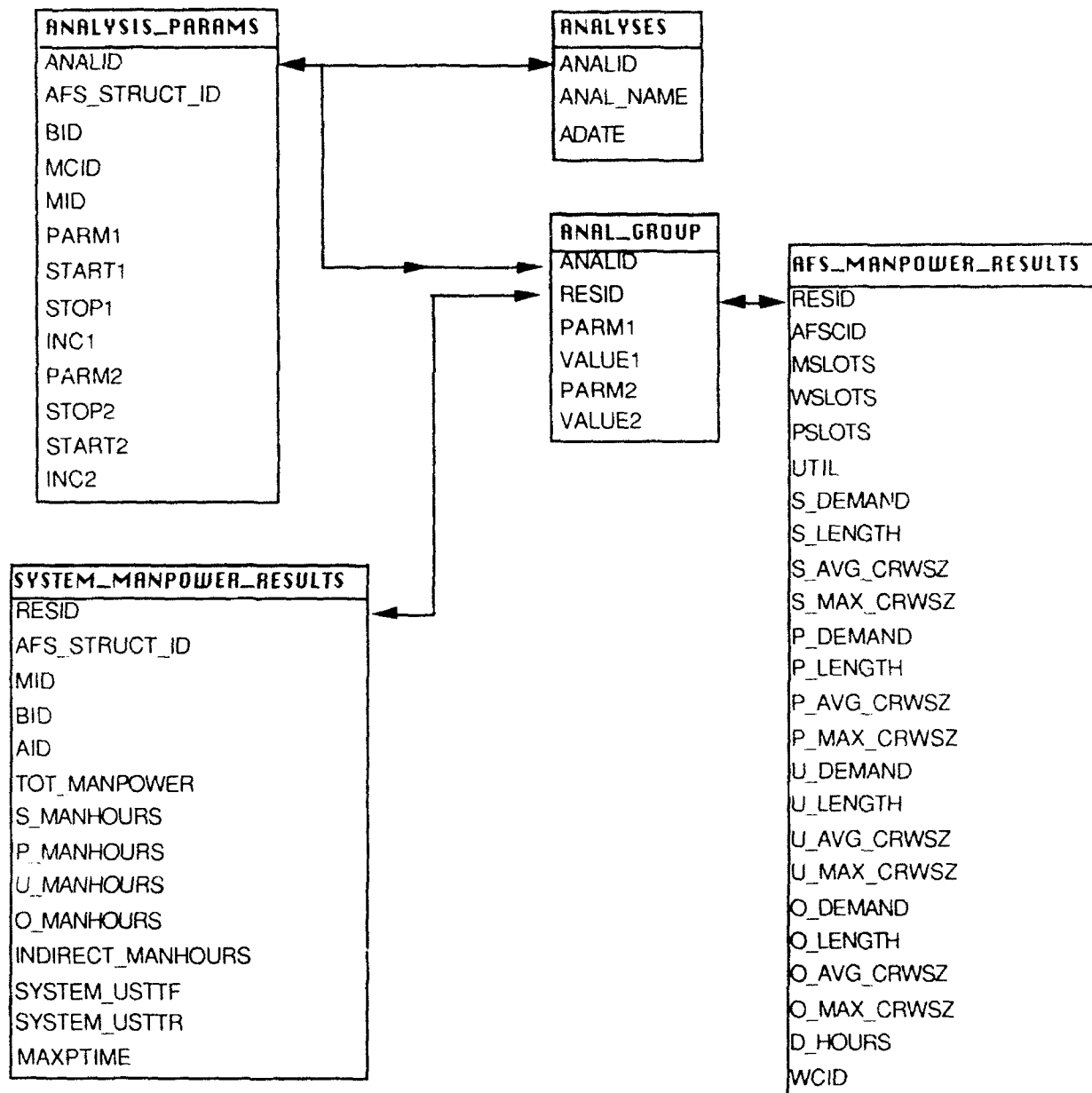


Figure 8
Reports Data Schema.

Figure 8 shows the structure of the output data, although some output (e.g., a new AFS structure) may be held in the tables from Figure 7. The data are organized by analyses, which are collections of individual results. An analysis is requested by an ANALYSIS_PARAMS table entry which defines the base, mission, and maintenance concept for the analysis. The various results are related by being outcomes from analyses produced by stepping one or two parameters across a range of their parameters. The SYSTEM_MANPOWER_RESULTS table contains information of interest about the entire scenario, such as total manpower and R&M information. The

AFS_MANPOWER_RESULTS contain information about the workload and manning for a particular AFS/work center combination. The S, P, U, O, and D prefixes on the R&M data relate to the currently defined maintenance types: scheduled off-equipment, scheduled on-equipment, unscheduled on-equipment, unscheduled off-equipment, and duty types.

Data Editing Functions and User Interface

Data editing functions and user interface will follow the model developed in IMACAD. The "data" referred to in the description of user functions, which follows this paragraph, consist of the WUC designator, descriptive name, alternative designator, time to failure (TTF), type of failure mechanism, time to perform task, task time distribution, task type (e.g., on-equipment, back shop, indirect, inspection, pre/post flight, etc.), alternative AFSs, and work center, sortie, or aircraft to which the task relates. These tasks can be associated with any combination of work center, aircraft, sortie, AFS, or LCOM network. Data entry and editing requirements are:

Enter Data at N-level WUC: the user can enter data at any level of detail.

Edit Data at N-level WUC: the user can edit any data element.

Roll data up from N to N-m level: The user can compress data to a lower (i.e., fewer WUC characters or more general) level of detail.

View N-level WUC at N-m level: The user can view data at their native level or any lower level of detail.

Edit N-level WUC data at N-m level: The user can edit data at the level he views them; changes are transferred to underlying data.

Batch edit: The user can select any set of tasks to edit (i.e., multiply by a constant, set to a constant, add a constant).

Expand Data from N to N+1 level detail: The user is led through a dialogue to expand data from a task at any level to the layer immediately beneath that level.

Merge range of data from data bank: The user can perform merges/replacements of any size from other aircraft/base/sortie/AFS task collections.

Data Analysis/Presentation Functions

The ability to generate an R&M report for any combination of work center, aircraft, mission, AFS, or associated tasks will be provided. Summary statistics will include TTF, MMH/FH and/or sortie, and average maintenance times (time to repair (TTR)) by maintenance type, average crew size, and composition. These reports will help validate the data of an emerging system and could also be used for early R&M analysis in system development.

The proposed system will adapt the analytic manpower analysis strategy first developed in IMACAD (Miller & Boyle, in press) and expanded upon in the TDSTL II effort. Thus, the R&M reports will include manpower-by-AFS statistics along with the customary task times and frequency data. The addition of the training data will necessitate additional reporting, authoring, and editing facilities to allow the training courses and associated behavioral objectives to be arranged by task, AFS, work center, WUC, or aircraft type and printed or displayed for the user.

Reporting Functions

The fixed steps of systems engineering and the Weapon System Acquisition Process, along with the unavoidable serial nature of the analysis process and the tendency for bureaucracies to specialize and compartmentalize responsibilities, have produced a disjointed logistics analysis community. The extreme example is, of course, the ISD/LSA schism, but other examples abound.

One symptom of the lack of communication within the logistics community is that successive steps of the process tend to treat their input data—that is, the data provided them by previous steps within the chain of analysis—as fixed quantities rather than ranges or potential trade-off relationships.

The R&M/manpower connection is of interest in this regard. The manpower analyst rightfully assumes the mission essential reliability requirements to be fixed, then adopts the comparability baseline system to meet the sortie and R&M parameters specified in the requirements documentation. A manpower estimate is subsequently produced. This number does nothing to inform R&M, equipment design, maintenance planning, or any other portion of the logistics system beyond the training and personnel communities, as outlined above. Moreover, potential trade-offs—such as the relationship among manpower, AFS structure, and maintenance concept and organization—are not addressed.

The lack of subsequent communication between the engineering and manpower communities is worth examining. Feedback from manpower to R&M management and planning should permit the ready assessment of changes to manpower requirements from a change in either the reliability or maintenance time or concept (e.g., a change from on-base to off-base repair for an item). As discussed above, the trade-off between task frequency and task length is not as predictable for manpower-by-AFS as it is for MMH/FH. A hypothetical relationship between frequency and time for manpower is presented in Figure 9. The isobars are the lines on the R&M curves relative to the baseline where manpower levels are the same. The graph is not intended to represent a known relationship, but should be interpreted as indicating that increases in maintenance times would be less deleterious to manpower than would decreases in reliability.

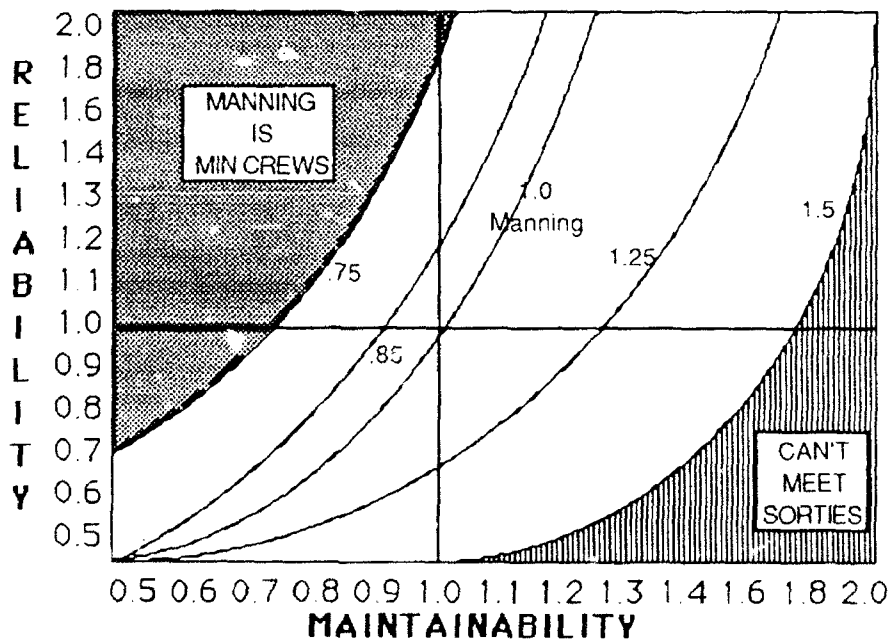


Figure 9
R&M Manpower Trade-off Curves

The present effort proposes to generate trade-off information of this sort with manpower estimates for use in R&M management. This should support the R&M management process in the same fashion as does the maintenance-manpower-per-flight-hour centered approach, but allow direct management of maintenance slots and (with the addition of training, personnel, and cost models) MPF costs. Parameters available for trade-off analysis of this type include R&M (times and crew size) parameters by maintenance type, sortie rate and length, and PAA.

The benefits of AFS restructuring can also be approximated numerically. Figure 10 presents results from a hypothetical analysis of AFS restructuring within a single work center. The baseline condition (15 AFSs) requires 58 persons. The manpower estimate for 14 AFSs would be derived by removing an AFS, reapportioning its workload to the remaining AFSs, and recomputing manpower with the resultant AFS structure. By repeating this process using several different AFSs, a stable estimate of the resultant manpower requirement would result. The process would be repeated for the other AFS levels, resulting in a numerical estimate of the value of compressing AFSs for a given maintenance scenario.

Automating the procedure to select the AFSs that will produce the maximum return for AFS combination would consist of removing the AFS with the lowest utilization for decomposition or selecting the two with lowest utilization for consolidation into a single AFS. Computationally, it would be easier to compute the effects of combining two AFSs than to decompose an AFS and distribute its workload to other AFSs as, in the former case, manpower would only need to be computed for the new AFS, not the entire work center.

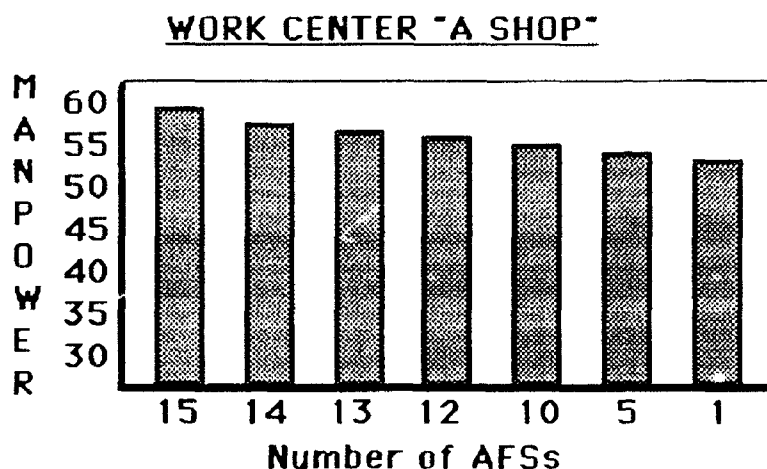


Figure 10
Numerical Prediction of AFS Restructuring Effects

An "optimal" AFS structure could be developed by clustering tasks according to their degree of training overlap as follows:

- 1) Select a maximum number of AFSs with which to populate the new AFS Structure.
- 2) Compute a measure of similarity between all task pairs from the amount of noncommon training they possess. This relationship is not necessarily symmetrical (e.g., if task A's training is a proper subset of task B's training, but there are two weeks of training within B, not in A, the distance from A to B is 0, while the distance from B to A is two weeks).

3) Moving from the smallest to the largest distances, cluster tasks according to their maximum distance (using the lesser distance as a tie-break, if needed). Recompute the training requirements for the resultant cluster after each combination. This will assemble all of the tasks that require less training under those that require the most training (i.e., group together tasks that require subsets of the most complex task's training requirements).

4) Stopping the process prior to developing the solution containing just one big AFS will be developed as part of the proposed effort, but the following are possible: a) fixed number of AFSs; b) manpower falls below some arbitrarily set limit; c) utilization reaches some predefined limit; d) total training length (i.e., \sum (number in AFS * training length)) is minimized; e) total numbers (i.e., Total Maintainers + Annual Attritions * training days/365) of individuals is minimized; f) ASVAB requirements of the maintenance cadre reaches some predetermined limit; g) MPT cost is minimized (via a combination of the issues addressed in e) and f) plus a cost model).

Note also that the stopping rules need to be applied to the entire AFS structure. Attempting to optimize some AFSs result in other AFSs possibly being suboptimal, thereby nullifying the manpower or cost gains made by the partial optimization on the considered AFSs.

It would be possible to levy additional constraints or goals on the optimal task clustering problem, such as fitting training length or ASVAB requirements to a fixed distribution, rather than imposing a limit to the total. It would also be possible to redefine the intertask distances as additional ASVAB requirements for the combined tasks. It is unclear whether this will be beneficial.

Implementation Environment

The proposed system will be developed on an MS-DOS platform in Microsoft Windows. The programming language will be C++ using the Borland Paradox relational data base manager.

Relationship to Logistics Support Analysis Record

One goal of this effort is to produce a Class 2 MIL-STD 1388-2B LSAR data automation system. That is, the system data will be mapped to their LSAR counterpart where possible, and the system will produce reports in LSAR format. However, some data will be external to LSAR and some will be in a different format. For example, LSAR handles task times by asking for (a) an average task time, (b) a maximum task time, and (c) the percentage of tasks that will exceed the maximum task time. This confusing scheme will not be adopted; we will carry this data as a distribution, a mean, and a variance measure.

V. WORK PLAN

The Phase II work plan describes the details of the proposed individual tasks, to develop the system described in Section IV. The effort will develop and validate a methodology for R&M/MPT and AFS structure optimization within a single weapon system. The resultant system will provide the means to generate R&M/manpower trade-off information allowing direct management of maintenance slots and MPT costs, instead of holding these parameters as constraints, as is currently the practice. The output of this system will provide several criteria to estimate the improvement offered by alternative maintenance/AFS/operational structures including a variety of cost breakdowns, total manpower, training load, personnel flow rates, and operational sortie rate at fixed manpower.

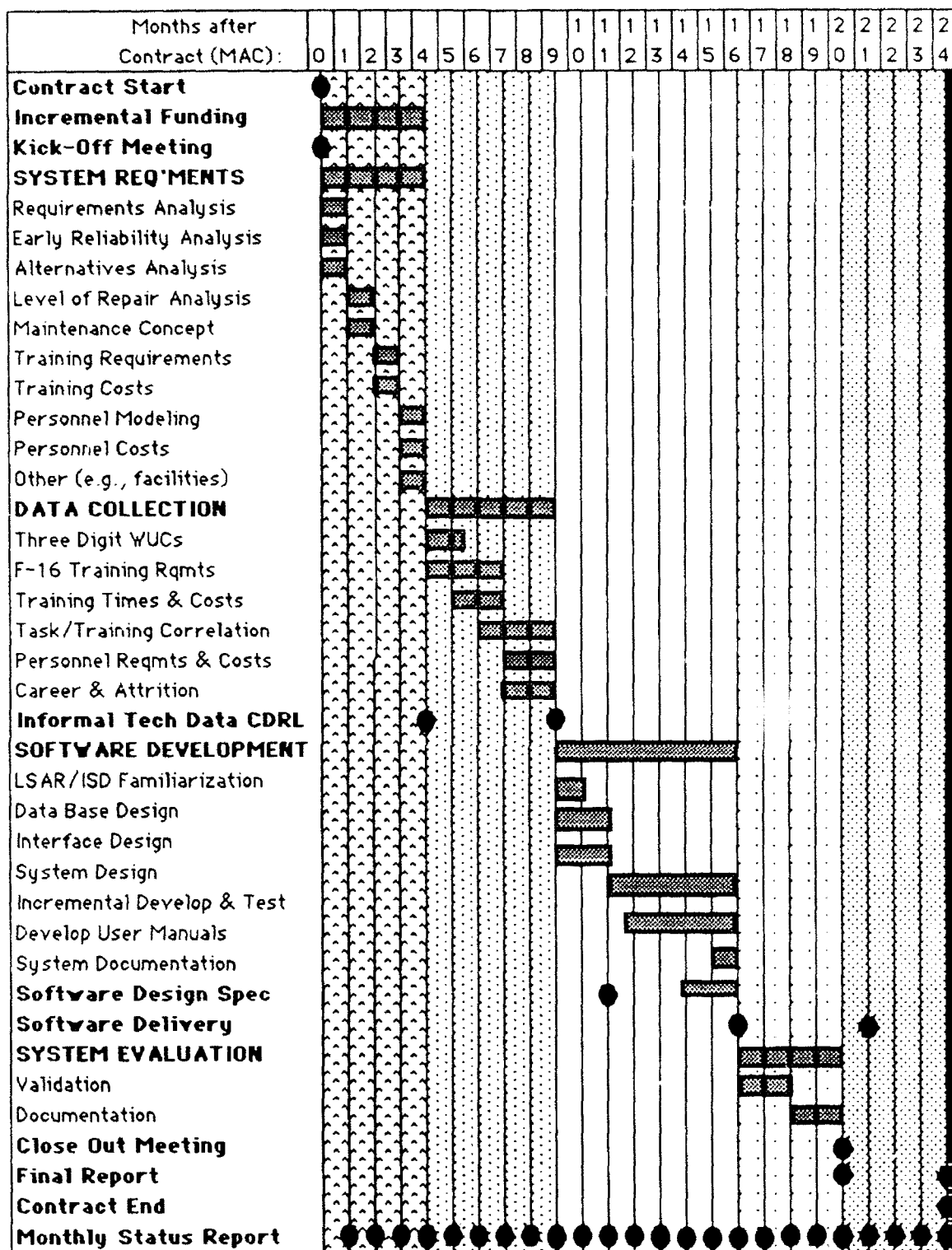


Figure 11
Proposed Phase II Schedule

The effort is divided into four activities: system requirements specification, data collection, software development, and system evaluation. The effort builds upon previous UES corporate and team member experience in automating integrated logistics support analysis tools. The schedule of tasks and milestones is presented in Figure 11.

System Requirements Specification

Analytic data manipulation, data requirements, and user interfaces will be completely specified during this activity, using the facility described in Section IV as a baseline for these developments. Since data to support the analyses is important to both the success of the Phase II program and subsequent users of the system, we will also use the requirements specification development to plan data collection. The third important job during this period will be in documenting the link between the LSAR data structure and the proposed analytic framework for use in software development.

R&M/MPT Analyses Supported

The requirements analysis for the proposed effort will consist of first developing a detailed presentation of our analysis, data, and user interface requirements. The UES project team will present these concepts to government experts in the various logistics areas and incorporate their feedback. These experts will be identified through personal contacts of the UES team members and government sponsors, and will mainly be WPAFB personnel. The program review at the end of this activity will present the detailed design to project monitors for approval. UES will identify and interview specialists in the following areas:

Requirements analysis regarding logistics is the initial determination of minimal critical system reliability and maximum inter-sortie maintenance times for competing system concepts. The usual means of handling reliability and maintainability in this analysis is to first determine the requisite availability for the aircraft if it is to meet the operational requirement. This high level analysis trades PAA against the system R&M profile (expressed as availability) to minimize expected system cost against the mission scenarios. Availability determines the critical system reliability and maximum allowable maintenance man-hours per flight hour. This, along with PAA, permits an approximate manpower estimate to be developed. The critical question is how early a comparison-based manpower analysis will be useful in providing manpower estimates from a closer view of the maintenance environment than is currently possible.

Early reliability and maintainability analysis breaks down the weapon system's R&M constraints into requirements for particular systems, as per the system engineering model. These requirements are successively refined and fed back to the design activity until the maintenance concept is formed. The proposed system will support the evolution of the R&M and maintenance concept data through this process, including facilities to analyze and report on the subsystems' definition and design at any level of detail available. The major addition to the current R&M process is the reporting of estimated manpower by AFS in addition to the maintenance manpower per flight hour statistic.

Alternatives analysis is the estimation of the relative burdens of alternative system and subsystem choices. The proposed tool will support this analysis by facilitating the side-to-side development and analysis of alternative models of the emerging system. The proposed system will be prescriptive in allowing the analyst to easily perform excursions upon the systems' major parameters to determine where opportunities exist for savings in MPT areas.

Level of repair analysis is an examination of the trade-off among reliability, repair strategy, manpower, spares cost, and support equipment requirements to achieve a given level of system availability. The proposed system will support this analysis through providing MPT costs for the

various support alternatives and allowing the analyst to combine and compare these costs with the less equivocal spares and support equipment costs. The requirements analysis for the present effort will examine the data requirements needed to allow trades against support equipment maintenance, spare levels to meet a given demand level, and depot maintenance costs.

Maintenance concept determination examines the association among work centers, level of repair, support equipment, and assigned AFSs. Since the work center is the arena where maintenance concept is explored, the proposed system relies heavily on work center attributes in building and evaluating base-level maintenance manpower. Consideration of issues such as shift policy, requisite supervision, allocation of indirect labor and duties will provide a unique analysis capability in this arena. Supporting maintenance concept analysis consists of providing the analyst the ability to develop and compare alternative work centers implementing the competing maintenance concepts. The major analysis issue in both this area and in the previous one is in developing accurate cost data against which to compare the MPT data generated from the proposed system. The data issue in supporting this analysis is the availability and format of data that usually flows from reliability-centered maintenance and level of repair analysis: if it cannot be assumed to exist within the LSAR structure.

Training requirements determination is the process of predicting AFS-specific and total force training requirements and the resulting burden upon the training system. This is currently performed by identifying changes to the predecessor system requirements: the proposed effort will replace this by developing data about the emerging system's total training profile. Early in the development process, this analysis will be comparison-based. Once the training/task correlation becomes available, the analysis will include determining localized impact of the new system on the training system through an exact determination of the training requirements for the proposed design. The critical analysis issue is the impact of the emerging system's training requirements on the baseline training requirements. The onus of developing training/task data for common use of this tool is one critical data issue. The type of data necessary to allow consideration of training delivery alternatives within the analysis is another critical data issue. The point at which the data are firm enough to allow analyses to analyze alternatives such as closed looping and AFS restructuring is the final critical data issue.

Training costs are the costs associated with delivering, modifying, and developing the training received by the emerging system's maintenance cadre. The training concept for a given training block drives the data requirements and sources: a classroom course's costs entail a development cost and a per-student cost for lodging, instructor, facilities, materials, etc., while a self-study course entails only a development cost and the trainees' time. OJT is somewhere between these two extremes. The critical analysis issue is determining when the emerging system's data has become firm enough to afford stable estimates of the new system's training burden. The critical data issue is how to develop prescriptive, design-relevant feedback to exploit the training cost statistics we are developing.

Personnel modeling is the determination of Air Force career paths, the projection of potential candidates' necessary attributes, and the projection of future recruiting requirements. The proposed system will provide a projection of the emerging system's force requirements to support the base level operation modeled, including numbers of personnel required per year of service and level. Resolving these data with force-wide concerns is the major analysis issue in this portion of the requirements determination for the proposed system. The correlation between the proposed system's data requirements and those available through specialists in force level personnel modelers and the availability of these data—the critical data issues—will also be determined in this activity.

Personnel costs include salary and support costs, recruiting costs, training costs, reenlistment bonuses, etc. The important analysis issue is in developing a suitably detailed cost

model without getting over complicated. The baseline data consist of an average cost by year of service. The exact determination of what this statistic needs to include is the major data issue of this portion of the effort.

Other features of the model are base level issues such as facilities and security requirements. The base fixed costs can be ignored within the context of the proposed system beyond the level of detail laid out in the LSAR requirements, but the costs that are variable and associated with manpower levels need to be identified and included in the system development.

Requirements Development Strategy

We will refine our requirements by interview. Our strategy is to identify experts and which of the R&M/MPT function presented in the preceding paragraphs they support, give them a general presentation of our goals and approach. We will then solicit their comments as we step them through our model of their process, and our interface concepts. At least two individuals representing each R&M/MPT function will be contacted. The team programmer/analyst will manage the requirements documentation since the requirements will eventually serve as the software design guidance.

Requirements Reporting

An informal technical data deliverable will be prepared and delivered four months after contract award documenting the results of the system requirements analysis. This deliverable will also include the data sources for all of the data identified as part of the requirements analysis. The impact of data shortfalls and workarounds will be provided as part of this deliverable. This information will also be presented during a review of the project to be held at the four-month juncture.

Data Collection

The testbed for the proposed effort will be the F-16 C&D wing at Shaw AFB, South Carolina. Operational and maintenance data will come from a combination of Maintenance and Operational Data Access System (MODAS), LCOM, and personal interviews. There are numerous sources of MPT data; the exact source(s) of each datum required for the effort will be presented as part of the requirements analysis effort's reporting efforts.

Other than the operational information, data requirements of the proposed effort are a) complete workload by AFS by work center data at the three-digit WUC, with additional detail where required to differentiate the domains of AFSs working under the same three-digit WUC; b) formal, follow-on, and OJT training requirements for each F-16 AFS; c) training costs for this training; d) associations between the training and the tasks; e) Mechanical and Electrical ASVAB subscale requirements for each F-16 AFS; f) career progression and attrition rates for each F-16 AFS and the personnel costs for recruiting and by year costs; and g) recruiting costs by ASVAB category.

Data Collection Strategy

The proposed effort will identify data sources as part of the system requirement determination process, and actually begin to collect this data as soon as arrangements for such can be made. This data will be assembled in the relational data base manager shell, the initial draft of which shall be put together during the requirements phase. Multiple sources of data will be consulted where possible, with data definitions and consolidation strategies from the diverse sources documented during the requirements determination activity.

Data Preparation

Associations between training blocks and task elements will be developed during this phase of the effort. In an ideal world, a level of task and training aggregation would exist where tasks would all be uniquely associated with day-sized chunks of training. As this is not the case, the task/training association activity will initially be restricted to one or two systems which are known to fall within the domain of a single AFS, such as, for instance, armaments or weapons. Some of the training—theory of operation, for instance—will cover large numbers of tasks and be indivisible, and easy to analyze. Other training may require we dig down below the three digit WUC task to get a pure match between training and duties. The prospect that this class of data cannot be reliably developed is the largest technical risk in the effort.

Data Reporting

An informal technical data deliverable at 9 months after contract award will document the data collection activity and present raw and summarized views of the data. Additionally, the baseline conditions that the data are intended to reproduce will be specified. The validation plan outlining these conditions will be presented at this time. Standard approaches to performing the functions of the proposed system will also be listed and provide a basis for the user evaluation of the system during the evaluation phase of the effort.

Software Development

The system will be implemented on a 66 MHz 80486DX personal computer in the Windows environment, using C++ and the Paradox relational data base kernel and library. This approximates the standard personal computer in use during the last half of this decade, and should provide reasonable performance with the proposed system; i.e., single workcenter analyses in seconds; single base model runs in 2–5 minutes; and runs with 25 to 100 excursions in one or two hours. A description of the hardware and software is included in the cost proposal.

The baseline version of the proposed system was described in Section IV. This description, recast more formally as the system requirements document and refined during the requirements analysis and data collection activities, will be the focus of the software design activity. Specifics of the software development are described in the following paragraphs.

Finalization of Data Dictionary

Final data base specification will expand the baseline data table definitions presented in Section IV to the requirements identified in the requirement determination and LSAR familiarization tasks. At the point in the program when software coding will take place, the data tables will have served as the basis for requirements definition and data collection, and contain the results of the data collection effort. If necessary, table definitions will be altered based upon that experience or anticipated problems in the subsequent software development steps. The internal variable labels to be used in the system will also be finalized.

LSAR/ISD familiarization will be a low level activity at the beginning of the proposed effort to acquaint team personnel with the new MIL-STD-1388-2B standard and to flesh out the proposed data model for requirements determination and data collection. Part of this will entail developing a cross-reference between the proposed system's data definition and the LSAR items they represent. The data related to training, personnel, and, particularly, costs are not all included in the previous LSAR definition. Differences between the proposed system and LSAR data describing substantially the same thing generally concern dimensions; e.g., the baseline data definition for the proposed system deals in months as the reporting unit, whereas LSAR usually prefers per year

numbers. The preferred rectification for these cases is to adjust the proposed system to the LSAR requirement.

One tie-in to a Phase III effort will be developed as a byproduct of the crosslisting of LSAR definitions. A strategy to expand the proposed system to an LSAR class 2 automation system through expanding the data base definition to the entire LSAR definition to be developed as part of the final report will be based on this activity.

Interface Specification and Considerations

Interface design will expand upon the baseline interface facilities described in Section 3 during the requirements determination process. Screen layouts for the various functions will be proposed and evaluated as part of the requirements. Previous experience on the IMACAD and TDSTL efforts have taught that the major problem will be to present appropriate information to perform a wider variety of data entry and edition jobs than might at first seem necessary. As a particular purpose will often have use for information from several tables, the screen that tries to handle too wide a variety of purposes can rapidly fill with information that is not of interest to all purposes, resulting in confusing dialogues or necessitating a plethora of separate, single purpose displays. A second, related problem was in helping the user move among dialogues; it often was necessary to add navigation shortcuts to individual dialogues to allow a user to move among several dialogues in the IMACAD/TDSTL application. Ultimately, this solution will lead to a having everything connected to everything else, which can also be confusing.

To surmount these human-interface problems two strategies will be adopted. First, the proposed effort will develop flow diagrams of user interactions across the data definition as part of the requirements analysis. These will be verified during the requirements interviews and compared against the proposed user interfaces to determine data requirements and navigation strategies. Second, the user interface will be developed using resizable windows to display information to the user. Standard dialogues will then be defined which configure the general dialogues to support particular purposes. Additionally, the user will be able to customize his own views to support his particular needs. For example, if a user is looking at the maintenance concept (task descriptions, systems, and AFSs for a particular work center) and wishes to compare two work centers, he could resize his initial display window to fit another work center's data onto the screen as well. The goal is to make the interface as flexible as possible without completely turning the effort into an interface development project.

Final Design

The final government-approved version of the system requirements will consist of a detailed description of the data processing requirements, the final data base schematic and data dictionary, and annotated pictures of the interfaces. This information will be the foundation for software coding and verification and for subsequent system documentation. This material will be internally reviewed by senior-level UES team members prior to coding, who will also aid the principal investigator and programmer in developing an activity checklist covering software coding and verification. A sample data set incorporating all of the system's data features will be developed and solved manually for the purpose of development testing.

Coding

Incremental coding and test of the software will proceed nine months after contract award, for a period of seven months. At this point, some form of the data entry and editing facilities will have been created to support data collection. This effort will be managed through the means of the activity checklist developed at the start of this phase of the effort.

Documentation

Development of the users' manual will take place as the software development process nears completion. The manual will cover development of system data, interfacing to another LSAR data system, a screen-by-screen description of data manipulation and analysis software, and on-line help covering the same material. This will be delivered with the software and programmers' documentation at the completion of the effort.

Software Reporting

System documentation will consist of the design and implementation documentation and extensively annotated source code. It will be delivered, along with the users' manual, as part of the project final report. It will be demonstrated to the government sponsors at the completion of this phase of the effort in a formal review 16 months after contract award.

System Evaluation

System evaluation will have two goals. The first is a computational validation of the system's outputs against Shaw AFB operational, manning, and utilization: if the proposed system generates the same utilization for the same manning and produces equivalent manpower by AFS by work center manning levels against the same scenario as the standard manpower system, then its manpower calculation will be deemed to work. Personnel requirements will be judged against the standard projections for these data and their costs. Training course requirements will be validated by the ability of the system to reconstruct the AFSs training requirements from the training to task data. The validation plan delivered as part of the data collection documentation will provide an output-by-output validation criteria set.

The second goal will be subjective evaluations of the system from potential user communities. The government may arrange for any number of demonstrations of the system during the four month evaluation period, including one demonstration to Pentagon MPT managers. Prospective users will compare the user facilities of the system against the competing set of approaches to solving the same problem identified during the data collection phase of the effort. A separate rating of the perceived utility of the system will also be collected, covering both the features that have a comparison system (e.g., the manpower calculation system) and features without a readily apparent comparison system (e.g., the early training/task association analysis). The results of both of these evaluations will be presented as part of the project final report.

The technical portion of the effort will be complete 20 months after contract award, at which time the software and final report draft will be delivered. A close-out meeting will also be held 20 months after contract award at Wright Patterson AFB.

VI. FURTHER DEVELOPMENTS

The proposed development effort will demonstrate the soundness of the Training/LSA and R&M/MPT integration strategy. Once this has been established, UES will be in an excellent position to provide subcontracting services to larger firms in developing comparability data bases and employing the proposed system on large development projects. Depending upon the

successful marketing of the company as an integrated logistics subcontractor, UES will continue system development to include a complete LSAR definition and support additional trade-off analyses not included in the proposed effort.

Training Materials/Task Analysis Integration

LSAR and ISD integration is one R&D area which can build upon the current effort. The training-to-task and training-to-AFS linkages from the present effort identify the particular training blocks associated with tasks and AFSs. The obvious expansion would be to manage the behavioral objectives for each training block during development, associating the behavioral objectives with training, blocks, tasks, and AFSs in an expanded LSAR data base. This would provide a more monolithic data integration between the ISD training and LSA task management responsibilities than the proposed approach of dealing with training data at the training-block level. The outcome would be an integrated task analysis/training materials authoring software system fed by the data architecture (with the behavioral objectives modification) proposed as part of this Phase II effort. Potential benefits include assistance in authoring both the instructional material and the task analysis data, automatic generation of training course content changes as a result of the development effort, and a closer monitoring of the training impacts of AFS restructuring, closed looping, and composite wing operations.

Task Analysis Product Integration

A further promising R&D area is the integration of technical order data generation with the system developed under the proposed Phase II effort and, if possible, the effort outlined in the preceding paragraph. This additional effort would develop and integrated technical data and instructional materials authoring system that is fed by the system proposed in this paper. The LSAR C Record task descriptions and associated training blocks (or behavioral objectives) could provide input to technical order generation and course material development for the ISA process. Additionally, scripts for some classes of training simulators could be generated during this process. Of possible help in this arena are developments from man-modeling. The automatic development of detailed task descriptions, either from heuristic planning algorithms working upon high-level (i.e., LSAR C Record) descriptions of tasks or from direct manipulation of the man-model within a CAD system, could reduce the manpower required for these activities by several fold while increasing their consistency.

The benefits from this effort would include the elimination of LSAR D Record task analysis. The training and technical orders that require this information would be generated directly from the more fundamental LSAR C Record and CAD data. HF and Safety analyses would be performed on the technical order data rather than on the task analysis data, eliminating one step in the process for these two disciplines. Inasmuch as task analysis often consumes most of the logistics analysis resources of a large development effort, the paybacks for the development of this technology would be enormous.

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